STATISTICAL STUDIES OF WORLD-WIDE SECCHI DATA

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THESIS

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WORLD-WIDE SECCHI DATA

by

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Statistical Studies of World-Wide Secchi Data

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ABSTRACT

An investigation was made to determine possible correlations between Secchi depths and other simultaneously measured oceanographic parameters which were on file at the National Oceanographic Data Center as of March 1972. Sixty-three one-degree sub-squares occurring in Japanese and Korean waters and eleven Atlantic and Pacific open ocean areas were chosen for linear correlation analysis using both sea surface data and mean values of some fourteen different oceanographic parameters averaged over the Secchi depth. In particular, oxygen measurements exhibited trends toward an inverse proportionality with Secchi depth while temperature indicated a possible direct proportionality.

Time series analyses of Secchi depths were performed and compared with upwelling indices computed for the Oregon coast and near Monterey Bay, California. An inverse proportionality and possible phase lag of mean Secchi depth compared to monthly upwelling index was observed. Multiple regression equations relating Secchi depth and upwelling index were calculated for both locations.

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I. INTRODUCTION

A. GENERAL

Optics, considered as a special branch of oceanography, has been the subject of renewed interest among oceanographers during the past few years. Solar radiation serves as the source of energy for the oceans, supplying them with heat and supporting their ecology through photosynthesis. Light is important for nekton and zooplankton of the ocean in finding their food and evading attack. Daylight and artificial lighting are also important for underwater viewing. And light may be used on occasion as an effective probe to resolve otherwise ambiguous measurements in physical oceanography.

Several applications of light to the study of the oceans have been noted. Tyler and Preisendorfer (1963) have classified these under three broad areas, including,

(1) Descriptive oceanography and other geophysical applications;

(2) Photosynthesis and other biological phenomena; and

(3) Image-recording equipment.

Duntley (1965) speculated on the possibility of conducting oceanographic studies by human observers in a Manned Orbital Research Laboratory (MORL). Among the potentialities discussed were the determination of sea state and surface wind velocity by means of visible light. He explained that the shape and size of the glitter pattern due to the

reflection of the sun by the surface of the sea is interpretable in terms of surface wind velocity, and that spatially averaged "inherent" radiance* of the ocean varies in a known way with sea state.

The above potentialities have been achieved to a limited extent in recent years by the use of satellites such as Skylab and ERTS-1. Petri and Starry (1973) have also established the feasibility of remotely measuring wind magnitude and direction in a real environment by the use of pulsed laser systems.

Growing attention has been attracted to the possibility of characterizing water masses by means of their optical properties (Jerlov, 1968). For example, Pak and Zaneveld (1973) traced the Cromwell Current to the east of the Galapagos Archipelago using optical techniques.

Among important applications of optical oceanography, one of the most important is in the field of marine biology. The physics of radiant energy is of direct importance for evaluating the photosynthetic activity in the sea. Optical measurements have served as a valuable aid in locating areas of high biological production and potential fishing grounds. Duntley (1965) has pointed out that multi-spectral photography conducted from an MORL should enable a quantitative assay of chlorophyll in sea water, and that other biological features of the ocean, for example, the occurrence and

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*Radiance is flux per unit projected area per unit solid angle in a specified direction.

distribution of red tide, should be observable under clear weather conditions. Clarke, et al. (1970) have shown that spectral measurements of backscattered light can be used to determine the abundance of chlorophyll as well as to trace currents, pollutants, or other significant materials in the water.

The work of Duntley (1952) emphasized the importance of underwater lighting for vision, television, and photography. He explained the importance of quantitative prediction of the irradiation produced at the object, on its background and throughout the observer's path of sight by incondescent lamps or flash tubes. This can enable optimum lighting arrangements and camera positions to be planned in advance and exposure to be predicted with sufficient accuracy to permit high-contrast photographic techniques to be employed effectively. Duntley (1971) explained that the greatest hope for truly long range underwater imagery is by means of pulsed lasers and gated electro-optical cameras.

Scatterance and beam transmittance meters are commonly used in the field of pollution research. Another frequently employed measurement scheme involves the use of fluorescent dyes as tracers in order to study diffusion in the sea.

B. BACKGROUND ON THE SECCHI DISC

The Secchi disc is one of the most widely used devices for measuring ocean water transparency. The disc was first mentioned in a published report by Commander Cialdi in 1865 and recently translated into English by Collier (1968).

Cialdi's report contained a scientific diary by Professor Secchi in which the factors affecting the visibility of a disc when lowered vertically in the sea were examined. These factors included disc color, solar altitude, sea surface reflections and refractions, ship's shadow, sky clearness, water color, disc diameter, and the height of the viewer above the water surface. Secchi observed an increase in depth at which the disc disappeared from sight associated with increased disc whiteness, solar altitude, sky clearness, and disc diameter. He noted that image dissection by surface refraction caused the visibility of the disc to decrease, and that the ship's underwater shadow also influenced its visibility. He also demonstrated the detrimental effect of surface reflections on the measurement and recommended a wide shadow over the place where the observations were being made.

Secchi's work established the experimental procedure for obtaining transparency with a Secchi disc, and in the years following his work, the Secchi disc became a widely used oceanographic tool. However, Tyler (1968) noted that it was never really standardized. That is to say, it was used widely because of its simplicity, but its physical properties were never fully specified. Holmes (1970) also noted that both disc diameter and reflectance have never been standardized or specified. Postma (1961) observed the

following limitations of Secchi disc measurements compared to measurements carried out by submersible K_--meters:*

(1) Secchi measurements can only give information on the extinction in surface waters and they can only be carried out in daylight of sufficient brightness, whereas irradiance measurements can be performed to somewhat greater depths.

(2) When using a Secchi disc no continuous registration is possible, nor are determinations at various wavelengths, whereas the use of appropriate filters in a K_--meter allows recording continuously with depth.

(3) Finally, the result of a measurement with a Secchi disc depends upon the visual acuity of the observer and on the daylight illumination and reflection from the sea's surface, which is not the case with a K_--meter.

Because of these limitations and difficulties it might appear that Secchi measurements are of no great importance. On the contrary, they can give valuable results as will be shown below. The Secchi disc has been widely used because of its low cost and convenience, and considerable research has been devoted to its utility as a practical instrument for measuring water transparency.

Secchi depth measurements have been especially useful to marine biologists, who have established practical relation-

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*K_- is the diffuse attenuation coefficient, a measure of the exponential attenuation of downwelling irradience in the sea. Biologists often use the term "vertical extinction coefficient" to denote K_-. It is not to be confused with the beam attenuation coefficient ("c" or "α"), a measure of the total attenuation of a collimated light beam through a fixed path length.

ships between Secchi depths and vertical extinction coefficients. Holmes (1970) mentioned that it is common practice for biologists interested in primary production to consider the bottom depth of the euphotic zone* to be equal to three times the Secchi depth. An inverse relation between the amount of phytoplankton and the visual range of the Secchi disc has been observed by Atkins, Jenkins, and Warren (1954), Arsen'yev and Voytov (1968), Voytov and Dement'yeva (1970), and others. From data collected in the English Channel, Poole and Atkins (1929) developed a widely used empirical formula for approximating extinction coefficients:

$$K_{-} = 1.7/Z_s$$

where K_{-} is the vertical extinction coefficient and Z_s is the Secchi depth in meters. Murphy (1959) established a positive correlation between albacore troll catches and water clarity. He asserted that the Poole-Atkins relation can be used to approximate closely the horizontal visual range of albacore. The Poole-Atkins relation has also served as an aid in the investigation of primary organic productivity as demonstrated by Ryther and Yentsch (1957). Holmes (1970) investigated transparencies in Goleta Bay and suggested that for turbid water 1.44 is probably a more appropriate factor than 1.7 in the equation above in estimating extinction coefficients from Secchi depths. He also suggested that the relation between

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*Roughly the depth at which the downwelling irradiance (K_{-}) has decreased to 1% of its value at the surface.

Secchi depth and the 1% optical depth merits additional study to incorporate a wide range of Secchi depths.

Visser (1967) examined Secchi and seawater color observations from the North Atlantic Ocean and developed the following empirical relation relating Secchi depth and yellow content of seawater:

$$\frac{100}{Z_s} = 0.26Y + 1.9$$

where Z_s is Secchi depth in meters and Y is the percentage yellow calculated from the Forel color scale. However, he cautioned that the relation was valid only for the particular ocean area investigated. Frederick (1970) examined possible similar relations between Secchi disc observations and color codes for other ocean areas based on Visser's findings. Much variability was found to exist, and no simple empirical relation could be determined. Brown (1973) observed a similar pattern in relating Secchi depth and Forel color code as reported by Visser. Although he observed the same trend, no universal numerical relationship valid for all oceans was found.

Graham (1966) determined relationships between diffuse attenuation coefficients (K_-), reciprocals of Secchi disc readings, and color observations from data collected in the central and eastern North Pacific Ocean. He concluded that the Secchi disc is a useful tool, but that caution should be observed when extrapolating the relationship between Secchi

disc measurements and extinction coefficients from one oceanic environment to another.

Postma (1961) investigated the relation between Secchi depth measurements and suspended matter both experimentally in the laboratory and in the coastal waters of the Netherlands. He concluded that Secchi disc measurements are a valuable source for additional information concerning properties of suspended matter. Estimates based on the empirical relationships between diffuse attenuation coefficients (K_-) and amount of suspended matter per unit volume of sea water and Secchi depth discussed above are usually strictly valid only in one particular oceanic region and are not generally useful elsewhere. Although these estimates may have relatively large standard errors associated with them, they may be acceptable for certain types of work, such as in some areas of marine biology, where a high degree of precision and accuracy is not always required, or in marine geology, where gross measures of sediment transport are desired.

In developing practical relationships between Secchi depth and other oceanographic parameters, correlation coefficient analysis is considered to be a useful starting point. Brown (1973) conducted such an analysis on a worldwide basis using sea surface data. Because mid-oceanic data were sparse, nearly all areas analyzed were coastal areas subject to localized effects such as fresh water runoff and upwelling. With these limitations, no simple and consistent relations between Secchi depth and other

parameters were evident; however, several trends were noted. He found that oxygen measurements exhibited trends toward an inverse proportionality with Secchi depth, while bottom depth data indicated a possible direct proportionality. He also observed that lower salinity water and high amounts of silicate were associated with decreased transparency in coastal areas subject to fresh water runoff.

C. PURPOSE OF INVESTIGATION

In view of the studies discussed above it was proposed to continue the search begun by Brown (1973) for possible correlations between Secchi depths and other simultaneously measured oceanographic parameters in areas of high data density. Areas as small as one degree latitude by one degree longitude were chosen to avoid unnecessary averaging of data from varying water types and differing coastal influences but at the same time to maintain a high data density, insuring a fairly representative analysis.

Open ocean areas having no coastal-type influences, such as from fresh water runoff and upwelling, were also to be examined, since correlations determined for such areas might yield results which could be simply and accurately extrapolated to similar ocean areas. Resulting correlations from coastal and open ocean areas were then to be compared and consistent trends were to be noted.

Furthermore, it was proposed to compare correlations between Secchi depths and sea surface data and those between Secchi depth and mean values of oceanographic parameters

averaged over the Secchi depth. This was to determine the validity of the use of sea surface measurements conducted in past correlation studies of this nature (Brown, 1973).

In addition, monthly and yearly time series analyses of Secchi depths were to be performed and compared with upwelling indices computed from historical meteorological data by Bakun (1973) for the west coast of North America.

II. METHODS OF INVESTIGATION

A. DEVELOPMENT AND DESCRIPTION OF THE CORRELATION COEFFICIENT

1. Variance and Covariance

The variance and covariance are necessary in the development and formulation of the correlation coefficient. A brief description and a summary of these statistical measures are provided in this section (Dixon and Massey, 1957).

The variance, σ^2, is defined as:

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_i - \mu)^2$$

where N is the number of observations X_i and μ is the mean of the X_i, $\mu = \frac{1}{N} \sum_{i=1}^{N} X_i$.

The variance is concerned with a single measured variable. The object of statistical analysis is often directed at discovering relationships among two or more variables. The simplest way of determining a relationship between two variables is to compute their covariance, a measure of the common variance between two variables. This measure is hard to use directly but is very important in the development of more advanced analysis. The covariance between X and Y, with arithmetic means μ_x and μ_y, respectively, is given as:

$$\sigma^2_{x,y} = \frac{1}{N-1} \sum_{i=1}^{N} [(X_i-\mu_x)(Y_i-\mu_y)]$$

2. Correlation Coefficient

To put the variances of two individual variables and their covariance into a meaningful measure, the correlation coefficient is used. This statistic ranges from -1 to +1, where +1 correlation indicates that two variables are exactly alike, i.e., the rate of change in both is proportional. Zero correlation implies statistical independence or the absence of any association. Negative correlation implies opposite association with one another. That is to say, as one variable increases the other consistently decreases. The correlation coefficient is defined:

$$\rho_{ij} = \sigma^2_{ij} / (\sigma^2_{ii}\sigma^2_{jj})^{\frac{1}{2}}$$

where ρ_{ij} is the correlation between the i^{th} and j^{th} variable, σ_{ij} is the covariance between the i^{th} and j^{th} variable, and σ_{ii} and σ_{jj} are the respective variances.

B. METHOD USED IN OBTAINING CORRELATION COEFFICIENTS

1. Biomedical Computer System Program (BIOMED)

The Biomedical computer system programs were developed at the University of California at Los Angeles (Dixon, 1973). The programs were initially developed to handle extensive analyses of large amounts of data in medical research. However, they are written in such a way that a wide variety of problems may be handled by each program by specifying the appropriate parameters of the problem.

2. BIOMED 02D (Correlation with Transgeneration)

This program is designed to provide basic description and tabulation on raw data. The output consists of the sums, means, and standard deviations of all variables. In addition three matrices are provided. All three are square and symmetric with dimensions equal to the number of variables. The first and second matrices are the cross-product deviations matrix and the variance-covariance matrix respectively. The third matrix is the correlation matrix. The diagonal elements show the correlation of variables with themselves and, by definition, they should correlate perfectly. Hence, as a check of validity of the correlation matrix, the diagonal elements should all be 1.0. A sample output of this program is provided in Appendix B.

The two most significant features of this program are the Boolean selection of cases on input and the cross-plotting of variables on output. The Boolean selection enables the screening of cases in order to omit those of no interest.

The cross-plotting feature enables the user to identify a base variable and plot other variables against it on individual graphs. Transgeneration options are also available for use in this program.

III. ANALYSIS OF DATA

A. GENERAL

The primary oceanographic data used in this study were on magnetic tapes obtained from the National Oceanographic Data Center (NODC). The information included a global coverage to March 1972 of all NODC Secchi data plus all the other station data collected at the same time Secchi measurements were made, including all chemistry from 86,258 stations. Screening of data to simplify computer handling was conducted for a former study (Brown, 1973) and preserved on tape. The data used in the present study consisted of the following:

Secchi depth
Day
Year
Latitude
Longitude
Marsden square
Water depth
Forel color
Cloud cover
Month
Water temperature
Salinity
Sigma-t
Oxygen
Phosphate
Phosphorus
Nitrite
Nitrate
Silicate

Only those chemistry measurements obtained at depths above or at the same level as the Secchi depth at each station were employed. Sample pH, although available, was not used in this study.

The data were stored on disc at the Naval Postgraduate Computer Center for analysis. A previous inventory of the data indicated a sparsity of open ocean data and an abundance of data in some coastal waters, especially off Japan and Korea.

In referring to the geographical areas studied, a ten-degree latitude by ten-degree longitude Marsden square numbering system was used. Figures 1A and 1B show the global Marsden square coverage. In high data density areas Marsden squares were further broken down into one-degree sub-squares. Figure 2 shows the one-degree division numbering system used.

B. LINEAR CORRELATION ANALYSIS

1. Japanese and Korean Waters

a. Correlations Using Sea Surface Chemistry Values

Due to the great relative abundance of data in Japanese and Korean waters, they were selected for initial analysis. They fall within Marsden squares 130, 131, and 132, which were broken down into one-degree subsquares. After preparation of a data distribution inventory, the 63 subsquares indicated in Figures 3A and 3B were chosen for linear correlation analysis. Coefficients and cross-plots were then obtained using Secchi depth measurements as a base variable against latitude, longitude, water depth, Forel color, cloud cover, month, and all sea surface chemistry measurements.

b. Correlations Using Mean Chemistry Values

Upon completion of the initial correlation analysis, 21 previously chosen subsquares were selected for further analysis. Correlation coefficients and cross-plots were again obtained using mean values of parameters averaged over the Secchi depth at each station. Temperature, salinity, sigma-t, and oxygen were selected on the basis of consistency of correlations and data density. A sample program used for averaging the parameters is provided in Appendix A. Screening was necessary in both analyses to eliminate stations with erroneous or questionable data.

2. Open Ocean Areas

Although open ocean data were limited, 11 areas were selected for correlation analysis.* These included six areas in the Pacific Ocean and five areas in the Atlantic Ocean and are shown in Figures 1A and 1B, designated by an area number. As can be seen from the figures, each of the areas selected in the Atlantic Ocean contains several Marsden squares. It was necessary to use more than one square in order to provide enough data for a reasonably representative analysis. All areas were selected to provide a sufficient data base and to minimize coastal influences such as fresh water runoff and upwelling. Correlation coefficient analyses were accomplished using both surface values of oceanographic parameters and the mean values of parameters averaged over the Secchi depth.

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*The boundaries of these areas are given in Table V.

C. TIME SERIES ANALYSIS

The purpose of a time series analysis was to group Secchi depths by month and year and to compute average Secchi depths by month. The resulting average Secchi depths were then compared to previously computed upwelling indices along the west coast of North America. Appendix C is an example of the type of Fortran program utilized in the time series analysis. Coastal upwelling indices were obtained from Bakun (1973) for years 1946 through 1971. In addition upwelling indices were obtained for years 1972 and 1973 (Bakun, 1974). Figure 21 shows the data grid and intersections at which his upwelling indices were computed.

Bakun's monthly indices were based on offshore Eckman transport calculated from daily mean surface atmospheric pressure data. Summaries by quarter and by year were also included. In generating the indices Bakun estimated the daily mean wind stress on the sea surface at points near the coast, from this computed the Eckman transport, and finally resolved the component of Eckman transport perpendicular to the coast. The resulting "upwelling indices" have units of cubic meters per second per 100 meters of coastline. The magnitude of the offshore component is considered an indication of the amount of water upwelled to replace that driven offshore. Negative index values indicate onshore transport or convergence at the coast (downwelling).

The time series program was utilized for two areas for which upwelling indices were available to allow a comparison

between the indices and monthly Secchi depth averages. In addition to the NODC data, Secchi depth data were obtained from the Hopkins Marine Station of Stanford University. Since 1951 Hopkins Marine Station has carried on a continuous hydrobiological survey for the California Cooperative Oceanic Fisheries Investigations (CalCOFI) with cruises at approximately two-week intervals on Monterey Bay and including stations at the six locations shown in Figure 27.

IV. DISCUSSION OF RESULTS

A. LINEAR CORRELATION COEFFICIENTS USING SEA SURFACE CHEMISTRY VALUES

1. Japanese and Korean Waters

Summaries of data distribution, parameter mean values, and resulting correlation coefficients are tabulated in Tables I, II, and III respectively. They are listed according to Marsden square and Marsden subsquare numbers. Linear correlation coefficient graphs for most of the subsquares are plotted in Figures 4A through 4N, and several samples of cross-plots are illustrated in Figures 5 through 19. The data density codes used in the cross-plots are translated in Table IV.

As was expected (Brown, 1973) no consistencies in correlation coefficients between Secchi depth and latitude, longitude, cloud cover, and month of year were apparent. However, cross-plots of latitude and longitude served as a valuable aid in determining erroneous station positions. This was true where coastal boundaries were within the subsquare boundaries. Stations with inland position locations were then screened and discarded during analyses. Cross-plots of month of year were also valuable in determining if station densities were representative throughout the year. Although one might expect a dependency of Secchi depth on month of year due to varying sun altitude, it appeared that

other parameters and factors such as upwelling and fresh water runoff had a dominating influence on transparency.

Some parameters were not included in the correlation coefficeint graphs and cross-plot figures, although they may occur in the summary tables. This was due to a limited amount of data available for analyses and/or strong inconsistencies resulting from correlation analysis. The parameters excluded were phosphate, phosphorus, nitrite and nitrate. Correlations between Secchi depth and remaining parameters will be discussed separately. It should be noted that cross-plots of all paramater pairs were made for each ocean area studied. Figures 5-19, discussed below, were selected as representative or typical.

a. Color

Forel color as was to be expected (Brown, 1973) correlated more consistently than any other parameter, with negative coefficients resulting in all cases but one. The exception occurred in Marsden square 132, subsquare 38, and resulted in a slightly positive coefficient. Typical examples of Forel color plotted against Secchi depth are shown in Figures 5 through 7. Cross-plots of these two variables appeared to range from a nearly linear to a nearly exponential trend. The same ranges occurred in subsquares directly within coastal influences and subsquares having little or no coastal influence.

b. Bottom Depth

As was expected, bottom depth correlated positively. However, in a few cases negative coefficients resulted. Positive coefficients were especially pronounced in subsquares with shallow mean depths and well within the range of coastal influences. One would expect this result, considering the high amount of annual rainfall and runoff that occur in Japan and Korea. Large quantities of suspended and dissolved materials would be expected, resulting in decreased transparency in shallow coastal waters. Such a trend can be seen in Figures 8 and 9. Subsquares including waters with greater mean depths and with little coastal influence did not exhibit a pronounced trend. Coefficients for these subsquares varied from strongly negative to strongly positive. These observations appear to indicate that bottom depth has little or no influence on Secchi depth measurements in mid-ocean areas.

c. Temperature

In all but four subsquares, temperature exhibited a positive correlation. The four exceptions occurred in subsquares situated near or within bays and resulted in slightly negative coefficients. Cross-plot examples of temperature against Secchi depth are given in Figures 10 through 12. Figure 10 is for a shallow water, coastal subsquare, while Figures 11 and 12 are for deep water subsquares separated from coastal influences. The coefficients and cross-plots resulting from the temperature analyses indicate a strong

dependence between Secchi depth and sea surface temperatures. This is not surprising, especially in areas where upwelling results in lower temperatures and increased amounts of nutrients near the sea surface. This in turn would tend to enhance phytoplankton blooms and thus lead to lower Secchi depths.

d. Salinity

A consistent correlation or trend between Secchi depth and salinity was not apparent except in subsquares subject to high amounts of fresh water runoff. In these subsquares positive coefficients resulted and the cross-plots have an exponential-like character. This pattern is illustrated in Figure 13 and was not unexpected considering the high amounts of terrigenous suspensions that can result with fresh water runoff. However, in deep water subsquares away from coastal influence no consistent pattern or correlation was apparent. An example of a cross-plot for a deep water subsquare is provided in Figure 14.

e. Sigma-t

Due to inconsistencies in salinity patterns and coefficients no single general correlation was noted between sigma-t and Secchi depth measurements. However, the same exponential-like pattern exists for subsquares subject to fresh water runoff. Examples of patterns resulting from fresh water runoff and deep water subsquares are given in Figures 15 and 16 respectively.

f. Oxygen

In all but five subsquares oxygen exhibited negative correlation. The five exceptions resulted in slightly positive correlations and occurred in both deep and shallow water subsquares. Negative coefficients were expected due to effects of fresh water runoff and photosynthetic activity. Examples of both shallow and deep water subsquares are illustrated in Figures 17 and 18 respectively.

g. Silicate

No consistent patterns were noted between silicate and Secchi depth except in subsquares subject to fresh water runoff. An exponential-like pattern resulted in these subsquares and is illustrated in Figure 19. Brown (1973) also found a similar pattern existing in the vicinity of the Columbia River discharge along the Northwestern coast of the United States.

2. <u>Open Ocean Areas</u>

Open ocean areas were selected for further analysis to determine if the trends noticed in the Japanese and Korean waters held elsewhere. The areas are shown in Figures 1A and 1B and their boundaries are given in Table V. Special attention was given to trends resulting for deep water subsquares. Summaries of data distribution, parameter mean values, and resulting linear correlation coefficients are tabulated in Tables VI, VII, and VIII respectively. Graphs of correlation coefficients for most of the selected areas are plotted in Figures 20A through 20C. Results for the Atlantic and Pacific Oceans will be discussed separately.

a. Atlantic Ocean

For all areas selected in the Atlantic Ocean bottom depth and temperature resulted in weak positive correlation coefficients. A strong dependence of Secchi depth on temperature is again displayed for the open Atlantic waters. Forel color and oxygen also exhibited the negative correlations observed for the Japanese and Korean waters. However, salinity and sigma-t exhibited strong positive and negative correlations, respectively, in areas located north of 20 degrees south latitude, whereas in the Japanese and Korean waters much variability was found.

The correlation coefficient graph (Figure 20A) for areas located between 60 degrees north and 20 degrees south latitude was of particular interest. Because of the consistencies in correlation coefficients for several parameters it was felt that a fairly reliable relationship between Secchi depth and other simultaneously measured parameters might result from further analysis of this area.

b. Pacific Ocean

Unfortunately, data for analysis in the mid-Pacific Ocean were very limited in number. However, five areas in the western Pacific and one area in the eastern Pacific (Figure 1B) were selected for study.

Resulting correlation coefficients were highly variable for the areas analyzed, as can be seen from the correlation coefficient graphs in Figures 20B and 20C. Forel color again exhibited negative correlations except for

Area 9. The exception resulted in no correlation due to a standard deviation of zero in color. Bottom depth and temperature normally led to positive correlations. However, bottom depth correlated negatively in Area 6. This is believed to be the result of data from stations located in the vicinity of the Mariana Trench. Although great depths do occur at this location, low transparency may have resulted due to runoff from the nearby islands. Eastward of the trench, shallower waters and higher transparencies could be expected.

B. LINEAR CORRELATION COEFFICIENTS USING MEAN CHEMISTRY VALUES

Summaries of parameter mean values for seawater chemistry and resulting linear correlation coefficients are tabulated in Tables IX and X for the Japanese and Korean waters shown in Figures 3A and 3B. Similar summaries are also tabulated in Tables XI and XII for the selected open ocean areas indicated in Figures 1A and 1B. The use of mean values of parameters averaged over the Secchi depth according to the procedures previously outlined did not result in significant improvements in correlation coefficients over those based on surface values only.

C. TIME SERIES ANALYSIS

Marine pollution has resulted in long term changes in certain chemical parameters obtained along polluted coastal waters and in shallow seas. For example, dissolved oxygen content below the halocline has decreased during

recent decades while phosphate concentrations have been steadily increasing during the past six decades in the Baltic Sea (Fonselius, 1970).

Time series analyses were attempted for the Baltic and Red Seas to find possible long term trends in average monthly and yearly Secchi measurements as a result of increased pollution. Secchi data from NODC were compared to data collected in the Red Sea by Luksch (1901). Long term trends were not apparent for either of these areas based on the available data.

Time series analyses were further utilized to study the relationship between Secchi depth and upwelling index near the Oregon coast and for Monterey Bay. Results from these analyses are discussed in the following sections.

1. Oregon Coast

Unfortunately, insufficient NODC data were available for time series analysis for most of the areas for which upwelling indices were available. The only exception was in the vicinity of 45°N x 125°W near the Oregon coast (Figure 21). Sufficient Secchi data were available for analysis at this location for the years 1961 and 1962.

Three-month running means of Secchi depth and monthly upwelling indices are plotted in Figures 22 and 23 for years 1961 and 1962 respectively. An inverse relation between the two parameters was evident with a possible phase lag of mean Secchi depth compared to monthly upwelling indices. In Figure 22 the latter are seen to peak more than two months

before a minimum in the Secchi curve is reached, while in Figure 23 for the following year such a phase lag is not evident. The results were expected since upwelling introduces large quantities of nutrients to the euphotic zone and is thus conducive to high organic production, which in turn leads to decreased Secchi depths. Bakun's (1973) calculations show that near the Oregon coast upwelling is both less persistent and less intense than off the California coast to the south, where offshore Ekman transport is present throughout most of the year. In Oregon waters summer upwelling is seen to accompany the change in wind pattern from southwesterly in winter to northerly in summer. During 1961 and 1962 upwelling was strongest in July with values of 51 and 107, respectively, while yearly averages were -34 and -6.*
Upwelling values remained nearly constant throughout the summer of 1961. On the other hand, a rapid increase in upwelling was observed for July 1962, with a rapid decrease in the following months.

Anderson (1964) studied the seasonal and geographic distribution of primary productivity of the Washington and Oregon coasts as evidenced by data collected on 14 cruises conducted from January 1961 to June 1962. He observed a spring bloom of phytoplankton during May and a smaller autumn bloom in August 1961. However, a close inspection of seasonal and horizontal contours of primary productivity

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*The units associated with the upwelling index are $m^3/s/100m$. See p. 27 above.

revealed a steady increase from May through August near 45°N x 125°W off the Oregon coast. Anderson also found stimulation of production by coastal upwelling to be especially evident in August.

Figures 22 shows a rapid decrease in mean Secchi depth occurring from February through May and a smaller decrease from June through October. The rapid decrease is attributed to the spring bloom of phytoplankton observed by Anderson. However, a minimum in mean Secchi depth did not occur until October. Anderson noted that difficulty was encountered with the productivity measurements during his September-October cruise with too few values to contour adequately. Nevertheless, he did observe that the influence of coastal upwelling appeared to advance westward as the summer progressed with a maximum westward extent occurring in October.

A minimum value of mean Secchi depth was observed for May 1962 (Figure 23), again corresponding to a spring bloom of phytoplankton observed by Anderson. The increase in Secchi depth observed for the remainder of the year possibly may be attributed to the rapid decrease in upwelling indices after July.

Figures 24 and 25 are plots of Secchi depth versus upwelling index for years 1961 and 1962 respectively. Figure 26 gives a combined plot using data from both years. Regression equations and corresponding curves are also provided in the figures for each year, with a dashed

regression curve shown in Figures 22 through 25 and based on the two-year combined data. Table XIII is a tabulation of multiple regression equations of the form $Z_s = Z_s(U^{-1}, U, U^2, U^3)$, where Z_s represents Secchi depth and U represents upwelling index which resulted from the Oregon coast study. These were generated by using a stepwise regression subroutine available in the BIOMED program (Dixon, 1973). Several transgenerations of upwelling index were performed in constructing the equations, and at each step the transgenerated form which made the greatest reduction in the error sum-of-squares was added to the regression equation. At each step in the procedure the multiple correlation coefficients served as an indication of how well the regression equations fit the data.

The higher Secchi values occurring during 1961 compared with 1962 were probably the result of a somewhat lower yearly average in upwelling index. The regression curve for 1961 shown in Figure 24 approached a maximum Secchi value with decreasing upwelling indices. However, upwelling did not appear to be strong enough to result in a normal seasonal maximum productivity and a resulting minimum Secchi value as low as is usually found. Both a maximum and a minimum were approached by the regression curve for 1962 shown in Figure 25. This was also apparent in the regression curve for the combined data (Figure 26) with maximum and minimum calculated values of 19.3 and 8.3 meters respectively.

2. Monterey Bay

a. Relationship Between Secchi Depth and Upwelling Index

Secchi data were available for years 1968 through 1973 from cruises conducted by Hopkins Marine Station of Stanford University on Monterey Bay. A preliminary investigation revealed an abundance of Secchi data obtained from Hopkins CalCOFI station 3 for the four years 1970-1973 and from CalCOFI station 4 for year 1971. For this reason, and due to the distance separating the stations and the surrounding coast, stations 3 and 4 and years 1970-1973 were selected for analysis. The locations of the stations are shown in Figure 27. Unfortunately upwelling indices were not available for Monterey Bay. The indices used were calculated for the point 36°N x 122°W (Figure 21) which is approximately 52 nautical miles south of CalCOFI station 4.

In contrast to the Oregon coast Monterey Bay is a region of strong upwelling during much of the year. Peak upwelling values ranged from a low of 221 for June 1971 to a high of 297 for April 1970 with intermediate peak values during June 1972 and July 1973. Yearly averages were also high, the average index for the 4-year period being 116.

Mean monthly Secchi depths for CalCOFI station 3 and monthly upwelling indices are plotted in Figures 28 through 31, corresponding to years 1970 through 1973, respectively. Figure 32 is a similar plot for CalCOFI station 4 for 1971, and Figure 33 provides a quarterly plot for CalCOFI station 3 for 1970 through 1972. An inverse relation between

mean Secchi depth and upwelling index was observed in all cases. A phase lag of from one to two months in mean monthly Secchi depth was observed at station 3 for years 1970 through 1972. However, such a phase lag between minimum Secchi depth and maximum upwelling index was not observed for 1973 at CalCOFI station 3 or at CalCOFI station 4 for 1971.

Plots of mean Secchi depth versus upwelling index were again constructed for the Monterey Bay study. These appear in Figures 34 through 37 for CalCOFI station 3 corresponding to years 1970 through 1973 respectively. Figure 38 is a plot of 1971 data for CalCOFI station 4 and Figure 39 gives a combined plot of all data used in the Monterey Bay study. Regression equations and corresponding curves are again provided in the figures with a dashed curve (Figures 34-38) representing a best fit to the combined Monterey Bay data. A dashed curve representing a best fit to the combined Oregon and Monterey data is given in a quarterly plot (Figure 33). A tabulation of multiple regression equations and multiple correlation coefficients is provided in Table XIV.

The regression curve for 1970 approached a minimum in Secchi depth with increased values of upwelling. Downwelling apparently was not sufficient for a maximum in Secchi depth to be approached by the regression curves for both 1970 and 1971 (stations 3 and 4). Higher Secchi values occurred in 1972 as a result of a lower yearly average in upwelling index, and a maximum Secchi depth was approached by the 1972 regression curve. However, more scattering of

data points and a significantly lower multiple correlation coefficient resulted in the 1972 analysis compared to previous years. Scattering was even more pronounced in 1973, resulting in lower multiple correlation coefficients.

The regression curve resulting from the combined Monterey Bay data is shown in Figure 39. A minimum in Secchi depth was approached by the curve beginning at an upwelling value of approximately 200. On the other hand, downwelling was not sufficient for the Secchi curve to approach a maximum Secchi value for the overall Monterey Bay study.

A plot of mean Secchi depth versus upwelling index for all data used in both the Oregon coast and Monterey Bay studies is given in Figure 40. Both a maximum Secchi value of 18.7 and a minimum of 9.3 meters resulted from the overall regression curve, corresponding to low and high upwelling values of approximately -200 and 200 respectively.

b. Relationship Between Phytoplankton Wet Volume and Upwelling Index

Plankton hauls were conducted by Hopkins Marine Station during cruises made on Monterey Bay from years 1956 through 1967. Wet settled volumes of net phytoplankton were then measured, and monthly averages were tabulated using data taken at the six standard stations illustrated in Figure 27. The data were obtained from Hopkins, and a plot of monthly phytoplankton wet volume in milliliters against upwelling index was constructed and is shown in Figure 41. Unfortunately, plankton volumes and Secchi data were not

measured simultaneously, and a direct comparison between the measurements could not be performed.

Although there was considerable scatter, especially for high values in wet volumes, in general a direct proportionality existed. It is speculated that the scatter may be due to errors resulting from the technique used in the wet volume measurement. When the measurement is performed, complete settling does not always occur to produce a distinct boundary between the plankton and the liquid above. The incomplete settling may be the result of electrical charges existing in the plankton and lead to values in the measurement higher than would otherwise be obtained. Because of the scatter no attempt was made to establish a regression equation between the wet volume and upwelling index.

V. SUMMARY AND CONCLUSIONS

Secchi depth readings are influenced by many sea water parameters. Although linear correlation coefficients cannot determine the exact nature of these relationships, they do provide an indication of general trends. Forel color, oxygen, and water temperature appear to be the most consistent in their linear correlations with Secchi depth in both coastal and open ocean waters. Forel color exhibited trends toward an inverse proportionality with Secchi depth as previously indicated by Visser (1967). Oxygen measurements also exhibited trends toward an inverse proportionality with Secchi depth while temperature data indicated a possible direct proportionality. However, much variability was encountered in correlation coefficient values for coastal waters.

In shallow coastal water areas subject to high amounts of fresh water runoff bottom depth data indicated a direct proportionality with Secchi depth, and salinity and sigma-t exhibited positive correlations with exponential-like patterns when plotted against Secchi depth. Silicate correlated negatively and also resulted in plots of an exponential-like character. Such special trends were not apparent in deep water not subject to coastal influences.

No consistencies in linear correlation coefficients between Secchi depth and latitude, longitude, cloud cover,

and month of year were found, and the scatter resulting from cross-plots of these parameters did not indicate possible consistencies in correlations of higher order. Nitrate, nitrite, phosphate, and phosphorus data were too sparse to allow representative analyses.

Linear correlation results from the Atlantic open ocean waters, including the region between 20 degrees south and 60 degrees north latitude, indicate a high degree of consistency in coefficients.

Sea surface chemistry values appear to be valid in correlation analysis based on the present study. The use of mean chemistry values of parameters averaged over the Secchi depth did not indicate significant differences beyond the use of sea surface values in linear correlations.

Although marine pollution in the Baltic Sea has resulted in long term trends of certain chemical parameters, especially evident below the halocline, Secchi values there do not appear to be significantly altered by such effects. Nor were long term trends evident for the Red Sea, an area for which Secchi data also span about seventy years.

An inverse variation between mean monthly Secchi depth and upwelling index was observed for coastal waters along the Oregon coast and for Monterey Bay. A "phase lag" was observed between the time at which minimum Secchi depth occurred and that at which maximum upwelling occurred.

Upwelling indices may be a valuable aid in the prediction of transparencies in coastal waters and in locating

areas of high biological production and potential fishing grounds. Although the regression equations resulting from the Oregon coast and Monterey Bay studies will not provide absolute values of Secchi measurements, a fairly reliable estimate should result when used in those areas studied, as indicated by high correlation coefficients. The regression equation, $Z_s = 13.83 - .04\ U + 3.13 \times 10^{-7}\ U^3$, with a multiple correlation coefficient of .80 resulted from the Oregon coast data, where Z_s is Secchi depth and U is upwelling index. A similar equation, $Z_s = 14.01 - .03\ U + 1.80 \times 10^{-7}\ U^3$, with a correlation coefficient of .72 was derived using combined data from both the Oregon coast area and Monterey Bay.

An inverse trend between phytoplankton wet volume and upwelling index occurred for data obtained for Monterey Bay. However, considerable scatter was observed, possibly resulting from the technique employed in the wet volume measurement.

VI. PROPOSED FUTURE RESEARCH

Work should continue to provide better world-wide coverage of Secchi disc measurements with the other oceanographic parameters normally sampled. To ensure this, a program should be established to provide better dissemination of oceanographic data - especially older data - from the various existing oceanographic institutions to NODC.

Studies relating Secchi disc measurements to other ocean parameters such as the diffuse attenuation coefficient should be continued to check further the empirical relationships that have been formulated and their spacial variability.

Both disc diameter and reflectance should be standardized or specified. Investigations should also be conducted to determine quantitatively the effects of varying sun altitude and wire angle on data taken with the Secchi disc.

As more Secchi data become available, time series analyses should be performed in shallow seas and coastal regions to determine any long term effects in water transparency due to the various forms of pollution.

Further research should be conducted in the Atlantic open ocean areas to study consistencies between the linear correlations between Secchi depth and other simultaneously measured parameters for the different regions.

Additional study should be devoted to the various upwelling regions of the world oceans to determine relationships

between Secchi measurements and upwelling indices to the end that standing crops may be predicted directly from the latter.

Table I. Surface Data Distribution by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
130	40	281	118	47	281	245	245	57	4			6
130	50	179	51	48	179	167	167	49	2			3
130	51	328	138	38	327	316	315	56	2			6
130	52	124	74	16	124	119	26	26	6			6
130	60	328	124	60	328	312	312	11				
130	61	306	120	29	304	285	283	51				
130	71	208	115	67	208		179	30				
130	81	216	97	59	216	198	198	35	7			10
130	82	270	93	40	270	238	238	75	10			9
130	92	744	159	180	744	607	607	99	14			14
131	00	224	104	62	224	215	215	112	59	4		31
131	11	229	168	30	229	137	137	38	15	3	6	7
131	15	200	48	37	200	189	189	138	31	6	10	25
131	23	298	169	52	298	231	231	47	13			20
131	25	214	61	49	214	206	206	120	34	6	10	21

Table I. (Continued) Surface Data Distribution by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
131	27	207	45	31	207	207	207	98	24		5	27
131	30	368	180	157	368	364	364	110	15			95
131	33	185	163	11	184	74	73	9	3			2
131	34	320	199	167	320	284	284	105	70			72
131	35	266	61	80	265	257	256	172	62	4	10	55
131	36	346	150	57	346	345	345	65	28	13		17
131	37	223	71	38	223	221	221	82	18		2	18
131	40	602	326	424	601	570	569	142	115	20		122
131	44	261	67	115	261	261	261	186	117			118
131	45	593		140	592	591	590	559	319			332
131	46	198	81	98	197	198	197	76	57			55
131	48	196	30	89	196	194	194	103	20		9	40
131	49	561	99	182	561	515	515	263	4			15
131	55	3399	433	761	3396	3179	3176	1892	700			1838
131	59	1051	117	467	1047	1006	1002	444	25			25

Table I. (Continued) Surface Data Distribution by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
131	60	227	175	15	227	202	202	16	13	4		12
131	65	677	284	226	676	663	662	246	81			227
131	70	395	257	22	395	380	380	24	22	7		22
131	77	354	153	47	354	255	255	16	8			9
131	78	365	310	168	365	339	339	3				
131	88	275	227.	83	275	261	261	19	8			6
131	99	223	179	80	223	218	218	23	3			4
132	09	89	34	22	89	86	86	52	16			10
132	19	163	79	63	163	161	161	106	65	6		51
132	28	289	87	206	289	288	288	200	43	3		83
132	29	1422	146	1103	1422	1380	1380	1078	351	2		458
132	38	103	74	92	103	95	95	34	22	6		25
132	39	548	266	391	548	537	537	161	57	2		112
132	44	114	98	100	114	107	107	27	19	16		36
132	45	320	279	289	320	310	310	47	38	20		16

Table I. (Continued) Surface Data Distribution by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
132	48	149	130	142	149	142	142	22	14	8		37
132	49	988	988	663	987	964	963	74	43	13		23
132	55	291	236	236	291	270	270	26	24	17		25
132	56	140	114	113	140	129	129	11	8	7		9
132	59	537	280	374	537	494	494	129	117	21		118
132	65	271	216	215	271	257	257	39	26	13		24
132	66	252	182	203	252	233	233	14	11	7		13
132	69	398	304	62	398	361	361	22	19	7		17
132	73	140	113	117	140	129	129					
132	74	344	290	290	344	308	308	8	6	6		6
132	75	245	187	196	245	220	220	25	23	15		21
132	78	115	76	39	115	103	103	8	8	4		7
132	79	501	363	70	501	482	482	37	35	17		30
132	81	104	79	84	104	87	87					
132	88	133	52	53	132	124	133	14	13			13

Table I. (Continued) Surface Data Distribution by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
132	89	162	77	6	162	157	157	6	6			6
132	98	360	234	90	360	331	331	18	18			18
132	99	83	63	3	83	78	78	3	3			3

Table II. Parameter Means by Marsden Sub-Squares
(Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 ($\frac{\mu g\text{-}at}{l}$)	NO_2 ($\frac{\mu g\text{-}at}{l}$)	NO_3 ($\frac{\mu g\text{-}at}{l}$)	SiO_4 ($\frac{\mu g\text{-}at}{l}$)
130	40	2.7 (1.4)	1866.8 (1488.8)	21.9 (3.9)	34.53 (.39)	23.80 (1.23)	5.28 (.61)	.05 (.05)			7.7 (3.6)
130	50	4.1 (1.9)	241.6 (312.6)	18.5 (4.9)	32.94 (2.99)	23.48 (2.56)	5.73 (.73)	.19 (.16)			12.7 (6.7)
130	51	3.5 (1.3)	1496.3 (1529.0)	19.1 (4.6)	34.19 (1.37)	24.31 (1.43)	5.49 (.60)	.11 (.06)			6.8 (1.9)
130	52	3.0 (1.1)	6258.3 (1880.2)	22.0 (4.0)	34.57 (.35)	23.85 (1.25)	4.97 (.35)	.23 (.18)			4.7 (2.5)
130	60	4.1 (1.5)	115.6 (158.9)	16.3 (4.7)	32.82 (3.57)	23.90 (3.04)	6.33 (1.17)				
130	61	3.3 (1.1)	602.5 (718.9)	17.0 (4.8)	34.03 (.66)	24.67 (1.25)	5.80 (.79)				
130	71	3.9 (1.3)	227.6 (211.8)	15.6 (5.7)	33.84 (.63)	24.81 (1.48)	5.71 (.80)				
130	81	4.4 (1.6)	163.3 (68.1)	15.5 (5.4)	33.07 (2.20)	24.29 (2.02)	6.48 (.85)	.27 (.19)			9.3 (2.9)
130	82	4.3 (1.3)	779.6 (519.9)	17.1 (6.0)	33.72 (.56)	24.40 (1.38)	6.23 (.96)	.36 (.34)			13.1 (8.4)
130	92	4.3 (1.4)	291.0 (309.9)	13.3 (6.3)	33.47 (1.00)	24.99 (1.47)	6.54 (.92)	.68 (.66)			14.1 (12.9)

Table II. (Continued) Parameter Means by Marsden Sub-Squares
(Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (°c)	Salin. (°/oo)	Sigma-t	O_2 (ml/l)	PO_4 (µg-at/l)	NO_2 (µg-at/l)	NO_3 (µg-at/l)	SiO_4 (µg-at/l)
131	00	2.4 (.9)	265.5 (151.9)	23.4 (3.8)	34.33 (.67)	23.25 (1.43)	4.91 (.33)	.17 (.13)	.12 (.06)		12.7 (8.6)
131	11	3.5 (.8)	670.9 (440.6)	24.0 (2.5)	34.15 (1.38)	22.99 (1.47)	4.91 (.29)	.28 (.25)	.04 (.02)	.21 (.31)	6.3 (3.1)
131	15	2.3 (.7)	4004.2 (638.1)	23.4 (3.7)	34.62 (.25)	23.44 (1.22)	5.01 (.36)	.12 (.11)	.08 (.10)	.18 (.25)	6.4 (4.4)
131	23	3.2 (1.2)	1013.7 (761.4)	23.0 (4.0)	34.42 (.53)	23.51 (1.47)	4.81 (.53)	.18 (.11)			8.4 (7.4)
131	25	2.8 (.8)	4063.9 (763.8)	23.2 (3.8)	34.47 (.39)	23.43 (1.31)	5.03 (.42)	.10 (.07)	.07 (.07)	.14 (.15)	8.3 (6.3)
131	27	3.0 (1.0)	4067.5 (264.2)	23.1 (3.9)	34.52 (.30)	23.50 (1.27)	4.95 (.40)	.15 (.26)		.27 (.29)	7.7 (6.9)
131	30	3.7 (.6)	37.1 (12.8)	19.3 (5.3)	33.74 (1.12)	23.87 (1.95)	5.15 (.53)	.41 (.18)			10.9 (11.1)
131	33	4.1 (1.0)	205.5 (255.7)	23.2 (4.2)	33.52 (1.53)	23.09 (2.03)	4.86 (.42)	.11 (.10)			7.0 (2.8)
131	34	4.5 (1.8)	155.0 (220.6)	22.2 (4.1)	33.02 (1.84)	22.69 (1.88)	5.20 (.57)	.21 (.19)			9.9 (4.0)
131	35	3.2 (1.1)	1320.5 (761.3)	22.4 (3.9)	34.12 (1.28)	23.40 (1.59)	5.04 (.36)	.19 (.17)	.04 (.03)	.16 (.14)	8.6 (5.7)

Table II. (Continued) Parameter Means by Marsden Sub-Squares (Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 (µg-at/l)	NO_2 (µg-at/l)	NO_3 (µg-at/l)	SiO_4 (µg-at/l)
131	36	2.7 (.8)	2011.8 (922.4)	21.0 (4.0)	34.49 (.66)	24.08 (1.35)	5.10 (.44)	.19 (.16)	.09 (.07)		8.8 (10.2)
131	37	2.7 (.8)	2775.7 (1051.2)	22.3 (4.1)	34.42 (.41)	23.64 (1.38)	5.05 (.40)	.20 (.15)		.39 (.25)	6.9 (3.3)
131	40	3.1 (.8)	117.9 (20.0)	19.9 (4.7)	33.80 (.96)	23.79 (1.84)	5.37 (.50)	.25 (.19)	.09 (.06)		11.7 (8.7)
131	44	7.9 (2.1)	40.4 (18.4)	18.6 (5.6)	31.85 (2.18)	22.62 (2.41)	5.52 (.61)	.26 (.21)			10.4 (4.8)
131	45		34.9 (78.0)	18.5 (6.2)	29.51 (4.73)	20.83 (4.27)	5.79 (.94)	.24 (.20)			17.7 (18.2)
131	46	3.2 (.9)	172.1 (330.1)	18.2 (5.3)	33.52 (1.86)	23.99 (1.70)	5.96 (.72)	.16 (.13)			17.4 (11.4)
131	48	3.0 (.9)	969.4 (821.2)	22.0 (4.0)	34.21 (.60)	23.58 (1.38)	5.19 (.65)	.23 (.28)		.19 (.07)	11.8 (5.5)
131	49	3.2 (1.2)	715.9 (641.3)	20.3 (3.9)	34.42 (.41)	24.18 (1.20)	5.41 (.52)	.28 (.22)			9.6 (4.4)
131	55	5.2 (1.7)	53.4 (44.3)	18.2 (6.1)	30.92 (4.27)	21.93 (3.52)	5.65 (.83)	.16 (.17)			11.1 (15.9)
131	59	7.9 (4.7)	182.4 (266.2)	18.2 (4.9)	32.87 (2.85)	23.49 (2.69)	5.76 (.62)	.39 (.25)			15.8 (6.4)

Table II. (Continued) Parameter Means by Marsden Sub-Squares (Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 (μg-at/l)	NO_2 (μg-at/l)	NO_3 (μg-at/l)	SiO_4 (μg-at/l)
131	60	3.3 (.7)	1362.3 (446.5)	17.3 (5.1)	33.85 (.73)	24.51 (1.67)	5.60 (.53)	.26 (.16)	.09 (.12)		13.6 (16.4)
131	65	3.9 (.6)	292.9 (154.4)	19.1 (5.7)	33.71 (.67)	23.91 (1.80)	5.32 (.62)	.13 (.12)			3.8 (2.7)
131	70	3.5 (.7)	1372.8 (489.4)	16.9 (5.7)	33.86 (.66)	24.55 (1.73)	5.58 (.53)	.31 (.24)	.08 (.08)		14.4 (16.2)
131	77	2.9 (1.3)	354.6 (442.0)	19.5 (4.8)	33.24 (1.66)	23.44 (1.90)	5.39 (.31)	.17 (.07)			6.3 (3.2)
131	78	3.8 (1.1)	92.5 (107.0)	17.0 (6.3)	32.79 (3.29)	23.60 (3.01)	5.32 (.14)				
131	88	3.5 (.7)	232.3 (175.4)	17.4 (5.8)	33.83 (.48)	24.35 (1.52)	5.35 (.51)	.26 (.16)			14.0 (20.8)
131	99	3.7 (1.2)	154.2 (183.6)	15.3 (6.1)	33.11 (1.39)	24.30 (1.77)	5.13 (.62)	.24 (.21)			8.8 (5.7)
132	09	2.9 (.7)	647.3 (209.2)	24.4 (3.5)	34.27 (.70)	22.97 (1.40)	4.82 (.29)	.16 (.11)			14.6 (10.7)
132	19	3.3 (.7)	416.4 (268.0)	21.7 (4.9)	34.04 (.84)	23.52 (1.90)	5.00 (.39)	.14 (.14)	.14 (.04)		16.4 (10.2)
132	28	3.3 (1.0)	136.6 (70.4)	21.2 (4.4)	33.88 (.99)	23.52 (1.83)	5.19 (.44)	.17 (.13)	.19 (.02)		12.1 (10.0)

Table II. (Continued) Parameter Means by Marsden Sub-Squares
(Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 $\frac{(\mu g\text{-at})}{l}$	NO_2 $\frac{(\mu g\text{-at})}{l}$	NO_3 $\frac{(\mu g\text{-at})}{l}$	SiO_4 $\frac{(\mu g\text{-at})}{l}$
132	29	4.0 (1.3)	111.4 (83.4)	21.0 (4.5)	33.70 (.97)	23.46 (1.77)	5.25 (.48)	.23 (.21)	.32 (.03)		16.0 (9.9)
132	38	2.9 (2.3)	128.4 (34.4)	22.6 (4.7)	33.45 (1.32)	22.93 (2.15)	5.51 (1.05)	.19 (.15)	.20 (.15)		12.7 (13.3)
132	39	3.4 (.8)	70.6 (31.0)	19.3 (5.2)	33.72 (1.18)	23.90 (1.99)	5.21 (.63)	.25 (.20)	.11 (.13)		14.4 (11.5)
132	44	4.1 (1.6)	86.7 (6.9)	18.0 (7.7)	32.14 (1.19)	22.84 (2.56)	5.28 (.79)	.30 (.22)	.10 (.07)		11.2 (12.7)
132	45	6.1 (2.2)	77.2 (22.3)	14.7 (6.9)	32.48 (.65)	23.88 (1.82)	5.40 (.75)	.31 (.21)	.07 (.05)		18.3 (22.4)
132	48	4.1 (1.6)	71.1 (34.8)	19.5 (4.9)	32.94 (1.94)	23.31 (2.38)	5.51 (.76)	.28 (.21)	.13 (.07)		7.3 (7.4)
132	49	3.1 (.9)	120.9 (74.4)	19.4 (4.8)	33.79 (1.09)	23.93 (1.97)	5.20 (.47)	.21 (.17)	.13 (.06)		11.6 (14.1)
132	55	5.0 (1.9)	66.4 (13.3)	14.9 (8.3)	32.07 (.57)	23.34 (2.07)	5.58 (1.01)	.29 (.15)	.07 (.06)		12.4 (13.7)
132	56	7.0 (1.6)	38.1 (9.9)	14.2 (8.6)	31.59 (1.70)	23.15 (2.48)	5.57 (1.12)	.41 (.20)	.06 (.04)		16.1 (18.8)
132	59	4.1 (1.5)	115.3 (36.0)	17.9 (4.5)	33.64 (1.05)	24.22 (1.78)	5.56 (.49)	.33 (.20)	.17 (.20)		13.1 (10.6)

Table II. (Continued) . Parameter Means by Marsden Sub-Squares (Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 $\frac{(ug\text{-}at)}{l}$	NO_2 $\frac{(ug\text{-}at)}{l}$	NO_3 $\frac{(ug\text{-}at)}{l}$	SiO_4 $\frac{(ug\text{-}at)}{l}$
132	65	4.3 (1.3)	54.5 (7.6)	14.9 (8.8)	32.03 (.45)	23.39 (2.07)	5.73 (.94)	.37 (.24)	.08 (.06)		13.3 (16.4)
132	66	6.2 (2.6)	25.1 (9.9)	14.3 (8.1)	31.58 (1.49)	23.18 (2.35)	5.59 (.88)	.46 (.34)	.09 (.08)		15.8 (21.2)
132	69	3.9 (.9)	102.3 (95.4)	16.3 (4.8)	33.81 (.76)	24.76 (1.58)	5.74 (.51)	.28 (.15)	.13 (.09)		15.5 (16.3)
132	73	4.6 (1.1)	70.3 (7.7)	17.3 (7.6)	31.55 (.56)	22.69 (2.02)					
132	74	5.4 (1.4)	70.5 (11.0)	14.9 (7.8)	31.69 (.75)	23.29 (2.02)	5.82 (.95)	.38 (.26)	.06 (.04)		11.7 (17.3)
132	75	7.6 (1.6)	43.3 (12.4)	13.9 (8.2)	31.38 (.94)	23.25 (2.09)	6.02 (.88)	.35 (.20)	.13 (.13)		14.0 (17.4)
132	78	4.0 (.5)	99.0 (100.0)	14.7 (6.3)	33.46 (.85)	24.61 (1.88)	5.87 (.65)	.45 (.27)	.06 (.02)		17.9 (16.3)
132	79	3.8 (.7)	253.9 (315.7)	15.2 (6.0)	33.76 (.63)	24.83 (1.69)	5.74 (.68)	.47 (.40)	.06 (.05)		13.7 (16.7)
132	81	5.1 (1.2)	48.5 (6.1)	14.8 (8.3)	30.91 (1.20)	22.86 (2.36)					
132	88	3.8 (.8)	297.8 (438.3)	13.8 (7.8)	33.37 (1.20)	24.70 (2.22)	5.93 (.58)	.23 (.10)			11.6 (1.9)

Table II. (Continued) Parameter Means by Marsden Sub-Squares
(Standard Deviations in Parentheses

Mar. Sq.	Sub-Sq.	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 $\frac{(\mu g\text{-at})}{l}$	NO_2 $\frac{(\mu g\text{-at})}{l}$	NO_3 $\frac{(\mu g\text{-at})}{l}$	SiO_4 $\frac{(\mu g\text{-at})}{l}$
132	89	3.5 (.7)	1420.3 (372.4)	14.9 (7.0)	33.59 (.49)	24.69 (1.69)	5.87 (.72)	.24 (.21)			10.7 (2.7)
132	98	3.6 (.6)	179.1 (351.0)	13.2 (7.0)	33.49 (.71)	24.98 (1.77)	6.03 (.75)	.25 (.14)			14.7 (12.5)
132	99	3.1 (.4)	2053.3 (639.5)	14.1 (6.8)	33.64 (.45)	24.93 (1.64)	5.27 (.16)	.17 (.14)			9.7 (1.5)

Table III. Linear Correlation Coefficients by Marsden Sub-Square.

Mar.Sq.	Sub-Sq.	Color	Bottom Depth	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
130	40	-.527	.313	.222	.138	.203	-.063	-.396			-.236
130	50	-.561	.424	.197	.431	.289	.044	-1.000			-.954
130	51	-.549	.380	.249	.264	-.078	-.210	-1.000			.672
130	52	-.445	-.279	.268	.113	-.223	-.409	-.309			-.817
130	60	-.569	.019	.104	.324	.250	-.705				
130	61	-.381	.317	.142	.232	-.045	.015				
130	71	-.472	.321	.244	.063	-.229	-.186				
130	81	-.338	.475	.140	.370	.212	.063	-.363			.543
130	82	-.244	-.036	.333	.173	-.322	-.251	.113			-.055
130	92	-.361	.156	.250	.262	-.119	-.252	-.528			.107
131	00	-.176	.006	.482	-.229	-.457	-.315	-.174	.897		-.153
131	11	-.698	.274	.246	.312	.034	-.644	-.584	-.952	-.892	.546
131	15	-.279	-.362	.553	-.306	-.528	-.410	.128	.569	-.590	.213
131	23	-.472	.053	.442	-.178	-.470	-.039	.378			.444
131	25	-.384	.146	.511	-.236	-.484	-.336	-.239	-.454	-.664	.228
131	27	-.264	-.065	.621	-.169	-.583	-.527	-.342		-.844	.189

Table III. (Continued) Linear Correlation Coefficients by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Color	Bottom Depth	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
131	30	-.534	.604	.227	.259	-.055	-.490	-.286			-.714
131	33	-.601	.054	.236	.378	-.065	-.352	.099			1.000
131	34	-.756	.322	.165	.575	.373	-.267	.049			.244
131	35	-.567	.344	.228	.365	.080	-.380	-.253	-.137	-.164	.012
131	36	-.563	.228	.515	-.128	-.475	-.474	.492	-.321		-.193
131	37	-.418	.123	.616	-.248	-.577	-.662	-.431		-1.000	.283
131	40	-.369	.177	.288	-.259	-.311	-.304	.054	.028		.308
131	44	-.700	.562	-.191	.420	.396	.118	.006			-.246
131	45		.205	-.073	.487	.434	-.230	.147			-.347
131	46	-.681	.389	.641	.637	.081	-.327	.380			-.695
131	48	-.474	.228	.434	.180	-.286	-.392	-.317		-.506	-.177
131	49	-.538	.172	-.029	.223	.089	-.116	.819			-.119
131	55	-.852	.752	.324	.491	.318	-.493	-.091			-.415
131	59	-.630	.516	-.016	.502	.419	-.368	.305			-.280
131	60	-.522	-.254	.265	-.306	-.307	-.320	-.424	.041		-.213
131	65	-.608	.217	.538	-.376	-.546	-.484	.039			-.086

Table III. (Continued) Linear Correlation Coefficients by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Color	Bottom Depth	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
131	70	-.636	.322	.467	-.322	-.467	-.543	-.620	-.176		-.008
131	77	-.421	.068	.463	.172	-.177	-.485	-.221			-.250
131	78	-.417	.349	.237	.365	.195	-.269				
131	88	-.003	.105	.565	-.064	-.530	-.502	-.015			.911
131	99	-.317	.491	.428	.411	-.125	-.284	-.437			-.073
132	09	-.022	-.248	.536	-.272	-.507	-.390	-.059			.092
132	19	-.553	.176	.512	-.402	-.502	-.559	-.237	-.028		-.257
132	28	-.519	.237	.347	-.379	-.395	-.236	-.280	1.000		.015
132	29	-.641	.468	.172	.216	-.046	-.296	-.095	1.000		-.083
132	38	.186	.276	.498	-.541	-.614	-.340	-.271	-.773		-.332
132	39	-.516	.693	.166	.126	-.055	-.029	.116	1.000		-.339
132	44	-.820	-.011	.851	-.630	-.826	-.836	.274	-.291		-.169
132	45	-.589	.350	.677	-.457	-.705	-.635	-.403	-.488		-.004
132	48	-.697	.640	.142	.214	.018	-.597	-.492	.136		-.120
132	49	-.486	.091	.334	-.221	-.307	-.150	.096	-.127		.065
132	55	-.559	.258	.730	-.340	-.726	-.878	-.157	-.614		.065

Table III. (Continued) Linear Correlation Coefficients by Marsden Sub-Square

Mar.Sq.	Sub-Sq.	Color	Bottom Depth	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
132	56	-.645	.040	.645	.102	-.395	-.634	.200	-.249		-.319
132	59	-.713	.623	.312	.029	-.191	-.229	-.050	-.179		-.120
132	65	-.608	.197	.723	-.262	-.697	-.615	.275	-.429		.090
132	66	-.140	.289	.592	-.073	-.466	-.542	-.431	-.149		-.174
132	69	-.521	.152	.248	-.228	-.254	-.172	.204	.215		-.285
132	73	-.572	.341	.621	-.331	-.574					
132	74	-.569	.403	.444	-.042	-.364	-.027	-.494	.031		-.399
132	75	-.422	.171	.376	-.056	-.306	-.658	.012	.398		-.120
132	78	-.489	.074	.223	-.178	-.265	.255	.181	.000		.677
132	79	-.515	.134	.259	-.339	-.339	-.026	-.160	.007		-.102
132	81	-.321	.137	.352	-.152	-.276					
132	88	-.438	.077	.248	.180	-.099	-.885	-.039			.108
132	89	-.261	-.432	.463	-.154	-.442	-.595	-.808			-.725
132	98	-.501	.288	.286	-.165	-.303	-.716	-.620			-.357
132	99	-.298	.529	.287	-.279	-.346	-.978	-.225			.000

Table IV. Data Density Code Used in Figures 5-19

The following table shows the symbols used in plotting frequencies of data in BIOMED 02D graphical output. For example, a symbol K represents twenty data points at a particular x-y coordinate.

DATA POINTS	SYMBOL	DATA POINTS	SYMBOL
1	1	21	L
2	2	22	M
3	3	23	N
4	4	24	O
5	5	25	P
6	6	26	Q
7	7	27	R
8	8	28	S
9	9	29	T
10	A	30	U
11	B	31	V
12	C	32	W
13	D	33	X
14	E	34	Y
15	F	35	Z
16	G	36-41	-
17	H	42-47	+
18	I	48-54	*
19	J	55-62	$
20	K	63+	/

Table V. Open Ocean Area Delineations

AREA	LATITUDE	LONGITUDE
1	40°-60° N	20°-40° W
2	20°-40° N	50°- 70° W
3	10°-40° N	30°-50° W
4	40°-50° N	140°-150° W
5	30°-40° N	160°-180° E
6	20°-30° N	140°-160° E
7	10°-20° N	130°-150° E
8	0°-20° N	150°-160° E
9	0°-10° N	160°-180° E
10	0°-20° S 10°-20° S	10°-30° W 0°-10° W
11	40°-60° S 40°-50° S	10°-50° W 0°-10° W

Table VI. Surface Data Distribution by Open Ocean Area

Area	Secchi Depths	Color	Bottom Depths	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
1	107	15	105	105	100	98	58	27	22		25
2	154	94	148	151	153	150	106	50	25	31	26
3	100	30	99	100	99	99	57	29	3	5	18
4	194	6	66	192	190	190	151	42	25	8	55
5	292	237	54	292	200	200	50	39	8	7	23
6	896	278	244	896	779	779	86	44	11	15	36
7	457	127	197	457	417	417	73	31	12	8	45
8	410	47	209	410	315	315	37	16	3	7	9
9	196	5	164	196	171	171	20	8			8
10	48	27	20	47	48	47	44	43	3		13
11	44		41	44	44	44	44	36	23	6	22

Table VII. Parameter Means by Open Ocean Area (Standard Deviations in Parentheses)

Area	Color	Bottom Depth (m)	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)	PO_4 ($\frac{\mu g\text{-}at}{l}$)	NO_2 ($\frac{\mu g\text{-}at}{l}$)	NO_3 ($\frac{\mu g\text{-}at}{l}$)	SiO_4 ($\frac{\mu g\text{-}at}{l}$)
1	3.1 (.9)	3316.4 (742.3)	12.1 (4.2)	35.28 (.52)	26.69 (.61)	5.85 (.59)	.45 (.25)	.15 (.09)		5.5 (2.7)
2	2.6 (1.4)	4338.2 (1290.2)	24.4 (4.2)	36.24 (.71)	24.40 (1.01)	4.77 (.58)	.07 (.04)	.08 (.11)	.04 (.04)	1.3 (.7)
3	1.9 (.9)	4288.8 (926.8)	22.6 (3.1)	36.65 (.45)	25.27 (.83)	4.77 (.27)	.11 (.07)	.11 (.08)	.06 (.04)	3.1 (2.2)
4	3.7 (.5)	4014.9 (777.1)	9.5 (3.9)	32.71 (.21)	25.21 (.65)	6.64 (.68)	.95 (.43)	.17 (.08)	.96 (.47)	20.7 (8.2)
5	2.7 (.8)	4657.1 (1268.1)	20.3 (3.2)	34.51 (.37)	24.05 (.97)	4.95 (.29)	.18 (.12)	.09 (.10)	.05 (.04)	6.6 (4.8)
6	1.6 (.7)	3944.8 (1578.8)	26.2 (2.9)	34.82 (.30)	22.77 (.89)	4.74 (.33)	.09 (.11)	.47 (.99)	.04 (.03)	4.0 (1.9)
7	1.6 (.6)	4773.0 (1293.4)	28.2 (1.6)	34.61 (.29)	22.03 (.50)	4.63 (.44)	.17 (.13)	.05 (.03)	.03 (.03)	7.7 (7.8)
8	1.2 (.4)	4449.8 (1226.4)	28.6 (.8)	34.57 (.38)	21.86 (.38)	4.50 (.13)	.16 (.08)	.08 (.06)	.06 (.01)	6.6 (4.8)
9	2.0 (.0)	4555.7 (569.9)	28.7 (.6)	34.47 (.34)	21.76 (.33)	4.46 (.09)	.26 (.13)			4.6 (2.2)

Table VII. (Continued) Parameter Means by Open Ocean Area (Standard Deviations in Parentheses)

Area	Color	Bottom Depth (m)	Temp. (^oc)	Salin. ($^o/oo$)	Sigma-t	O_2 (ml/l)	PO_4 $\frac{(ug-at)}{l}$	NO_2 $\frac{(ug-at)}{l}$	NO_3 $\frac{(ug-at)}{l}$	SiO_4 $\frac{(ug-at)}{l}$
10	3.3 (1.7)	4502.3 (1054.9)	26.1 (2.3)	35.77 (.34)	23.58 (.76)	4.54 (.49)	.18 (.10)	.18 (.05)		4.9 (1.8)
11		4535.2 (994.9)	8.2 (5.1)	34.36 (.56)	26.62 (.37)	6.55 (.87)	1.03 (.51)	.17 (.09)	.82 (.71)	13.6 (20.0)

Table VIII. Linear Correlation Coefficients by Open Ocean Area

Area	Color	Bottom Depth	Temp.	Salin.	Sigma-t	O_2	PO_4	NO_2	NO_3	SiO_4
1	-.739	.173	.443	.514	-.374	-.527	-.039	.117		.181
2	-.605	.309	.677	.506	-.447	-.717	.062	.199	-.151	-.018
3	-.327	.083	.557	.432	-.398	-.087	-.200	-.945	.698	-.527
4	-.598	.348	-.127	.253	.148	.084	-.027	.032	.337	.259
5	-.498	-.368	.557	.148	-.504	-.469	-.326	-.473	-.754	-.191
6	-.358	.069	.245	.142	-.242	-.131	.080	.042	.089	-.023
7	-.019	.206	.108	.001	.048	-.470	-.175	.152	.246	-.639
8	-.474	.171	.021	-.174	-.226	-.228	.321	.858	.949	.204
9	.000	.081	.242	-.452	-.482	.061	.460			.280
10	-.706	.171	.636	.337	-.496	-.397	-.175	-.907		.065
11		.006	.032	-.025	.015	-.223	.088	.168	-.455	-.204

Table IX. Parameter Means by Marsden Sub-Square Using Values Averaged to the Secchi Depth (Standard Deviations in Parentheses)

Mar.Sq.	Sub-Sq.	Temp. (^{o}c)	Salin. (^{o}/oo)	Sigma-t	O_2 (ml/l)
130	51	19.0 (4.5)	34.24 (.90)	24.37 (1.29)	5.55 (.61)
130	60	16.0 (4.5)	33.30 (2.05)	24.35 (1.97)	6.25 (1.12)
130	61	16.7 (4.6)	34.05 (.65)	24.75 (1.19)	5.80 (.74)
130	92	13.0 (6.1)	33.53 (.80)	25.10 (1.32)	6.56 (.97)
131	30	19.1 (5.0)	33.82 (1.02)	24.00 (1.80)	5.12 (.47)
131	34	22.1 (4.0)	33.25 (1.04)	22.90 (1.40)	5.18 (.53)
131	36	20.9 (4.0)	34.52 (.43)	24.11 (1.29)	5.09 (.45)
131	40	19.7 (4.6)	33.83 (.84)	23.86 (1.75)	5.38 (.50)
131	45	17.9 (5.8)	31.08 (1.94)	22.17 (2.22)	5.46 (.83)
131	49	20.1 (3.8)	34.43 (.36)	24.25 (1.14)	5.42 (.50)
131	55	18.0 (5.6)	32.58 (1.51)	23.26 (1.90)	5.50 (.72)
131	59	18.0 (4.5)	33.34 (1.74)	23.93 (1.80)	5.55 (.61)
131	65	18.8 (5.4)	33.73 (.63)	24.00 (1.71)	5.33 (.59)
131	70	16.6 (5.5)	33.88 (.63)	24.64 (1.65)	5.64 (.48)
131	77	19.4 (4.8)	33.27 (1.66)	23.50 (1.86)	5.40 (.42)

Table IX. (Continued) Linear Correlation Coefficients by Marsden Sub-Square Using Values Averaged to the Secchi Depth (Standard Deviations in Parentheses)

Mar. Sq.	Sub-Sq.	Temp. (°c)	Salin. (°/oo)	Sigma-t	O_2 (ml/l)
131	78	16.7 (6.0)	33.29 (1.43)	24.07 (1.89)	5.14 (.26)
132	29	20.7 (4.4)	33.77 (.83)	23.58 (1.65)	5.24 (.47)
132 ↓	39 ↓	19.1 (5.0)	33.82 (.98)	24.02 (1.82)	5.22 (.61)
132	49	19.1 (4.6)	33.85 (.98)	24.04 (1.84)	5.27 (.45)
132	59	17.6 (4.4)	33.72 (.92)	24.35 (1.67)	5.53 (.42)
132	79	14.6 (5.6)	33.81 (.56)	25.02 (1.49)	5.91 (.62)

Table X. Linear Correlation Coefficients by Marsden Sub-Square Using Values Averaged to the Secchi Depth

Mar.Sq.	Sub-Sq.	Temp.	Salin.	Sigma-t	O_2
130	51	.260	.310	-.117	-.356
130	60	.104	.349	.222	-.725
130	61	.149	.226	-.051	.028
130	92	.266	.260	-.163	-.198
131	30	.207	.284	-.034	-.350
131	34	.179	.709	.324	-.209
131	36	.521	-.235	-.505	-.507
131	40	.297	-.292	-.323	-.317
131	45	-.029	.550	.380	-.025
131	49	-.008	.225	.061	-.185
131	55	.304	.474	.067	-.320
131	59	.041	.573	.402	-.058
131	65	.529	-.356	-.532	-.517
131	70	.471	-.327	-.473	-.629
131	77	.456	.175	-.161	-.516
131	78	.226	.430	.093	-.746
132	29	.183	.170	-.079	-.256
132	39	.167	.110	-.079	.037
132	49	.340	-.233	-.318	-.139
132	59	.356	-.037	-.258	-.125
132	79	.276	-.378	-.367	-.054

Table XI. Parameter Means by Open Ocean Area Using Values Averaged to the Secchi Depth (Standard Deviations in Parentheses)

Area	Temp. (^oc)	Salin. ($^o/_{oo}$)	Sigma-t	O_2 (ml/l)
1	12.4 (4.5)	35.29 (.52)	26.64 (.68)	5.82 (.57)
2	24.4 (4.1)	36.28 (.63)	24.43 (.98)	4.78 (.56)
3	22.6 (3.1)	36.65 (.45)	25.27 (.83)	4.77 (.24)
4	9.4 (3.8)	32.70 (.21)	25.21 (.63)	6.68 (.57)
5	20.3 (3.1)	34.50 (.36)	24.07 (.95)	4.94 (.29)
6	26.2 (2.9)	34.82 (.29)	22.80 (.88)	4.75 (.31)
7	28.2 (1.5)	34.60 (.33)	22.05 (.50)	4.62 (.36)
8	28.6 (.8)	34.58 (.37)	21.87 (.37)	4.51 (.16)
9	28.7 (.5)	34.48 (.34)	21.78 (.32)	4.44 (.05)
10	25.9 (2.4)	35.78 (.35)	23.64 (.74)	4.59 (.26)
11	8.7 (4.9)	34.39 (.56)	26.58 (.37)	6.45 (.80)

Table XII. Linear Correlation Coefficients by Open Ocean Area Using Values Averaged to the Secchi Depth

Area	Temp.	Salin.	Sigma-t	O_2
1	.528	.530	-.485	-.510
2	.664	.496	-.453	-.719
3	.543	.428	-.382	-.023
4	-.142	.265	.176	.083
5	.556	.147	-.501	-.429
6	.247	.139	-.236	-.150
7	.090	.121	.003	-.461
8	-.006	-.187	-.216	-.228
9	.235	-.468	-.490	.343
10	.629	.341	-.496	-.512
11	-.071	-.057	.173	-.104

Table XIII. Regression Analysis Results (Oregon Coast)

Year	Step	Regression Equation	Multiple Correlation Coefficient
1961	1	$Z_s = 13.91 - .03\ U$	.79
	2	$Z_s = 13.96 - .05\ U + 4.52 \times 10^{-7}\ U^3$	.85
	3	$Z_s = 14.23 - .05\ U - 1.66\ U^{-1} + 4.45 \times 10^{-7}\ U^3$	.86
1962	1	$Z_s = 13.66 - .03\ U$	.71
	2	$Z_s = 13.90 - .04\ U + 11.54\ U^{-1}$	.78
	3	$Z_s = 14.24 - .095\ U + 20.17\ U^{-1} + 5.57 \times 10^{-6}\ U^3$	.86
1961 and 1962 (combined)	1	$Z_s = 13.78 - .03\ U$	.77
	2	$Z_s = 13.83 - .04\ U + 3.13 \times 10^{-7}\ U^3$	.80

Z_s = Secchi Depth (m)
U = Upwelling Index (m^3/sec/100m)

Table XIV. Regression Analysis Results (Monterey Bay)

Year	Step	Regression Equation	Multiple Correlation Coefficient
1970	1	$Z_s=14.35-.02\ U$	.85
	2	$Z_s=14.95-.06\ U+1.44 \times 10^{-4}\ U^2$	.93
1971	1	$Z_s=9.11+38.64\ U^{-1}$	.82
	2	$Z_s=10.61-.01\ U+24.98\ U^{-1}$	.89
1971 (CALCOFI 4)	1	$Z_s=12.09-.02\ U$	.93
1972	1	$Z_s=14.66-3.80 \times 10^{-5}\ U^2$	.63
1973	1	$Z_s=12.15+1.12\ U^{-1}$	.28
	2	$Z_s=12.67+.93\ U^{-1}-1.60 \times 10^{-5}\ U^2$	.37
1970-1973 (combined)	1	$Z_s=13.35-.015\ U$	.57
	2	$Z_s=13.60-.02\ U+1.00 \times 10^{-7}\ U^3$	.59
1961-1962 1970-1973 (Oregon coast and Monterey Bay data combined)	1	$Z_s=13.87-.02\ U$	.69
	2	$Z_s=14.01-.03\ U+1.80 \times 10^{-7}\ U^3$	.72

Z_s = Secchi Depth (m)
U = Upwelling Index (m^3/sec/100m)

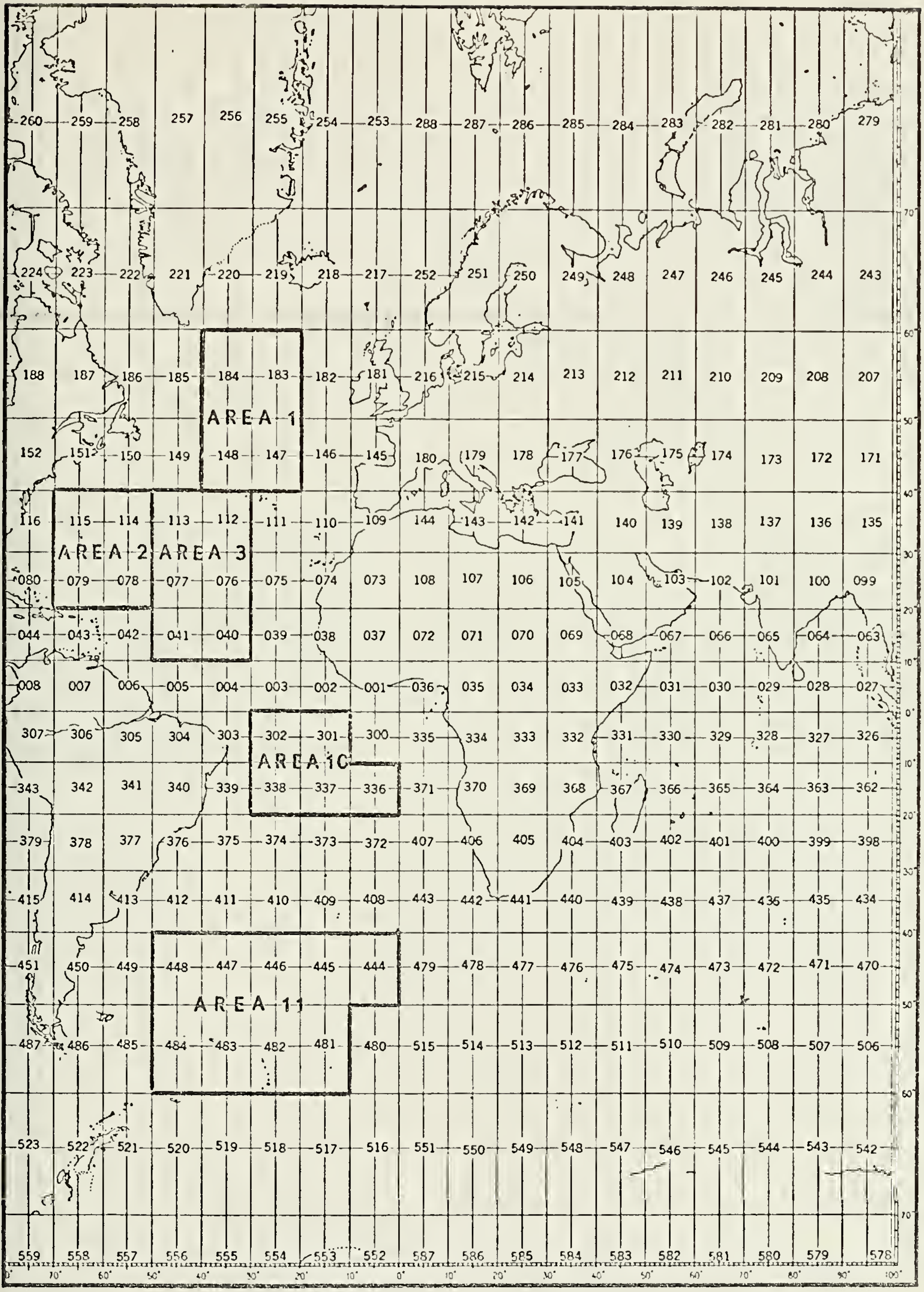

Figure 1A. Marsden square chart showing open ocean areas studied in the Atlantic.

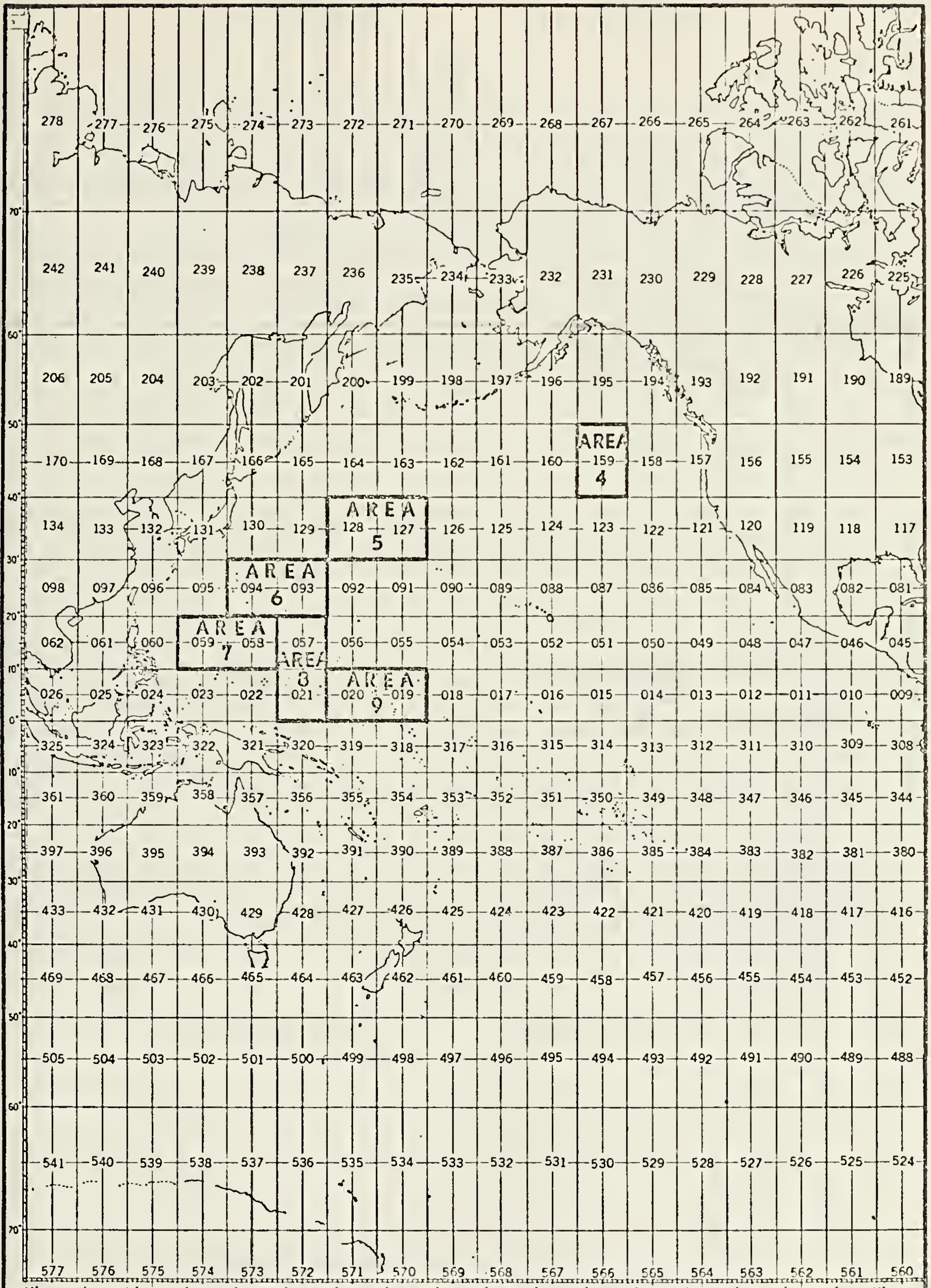

Figure 1B. Marsden square chart showing open ocean areas studied in the Pacific.

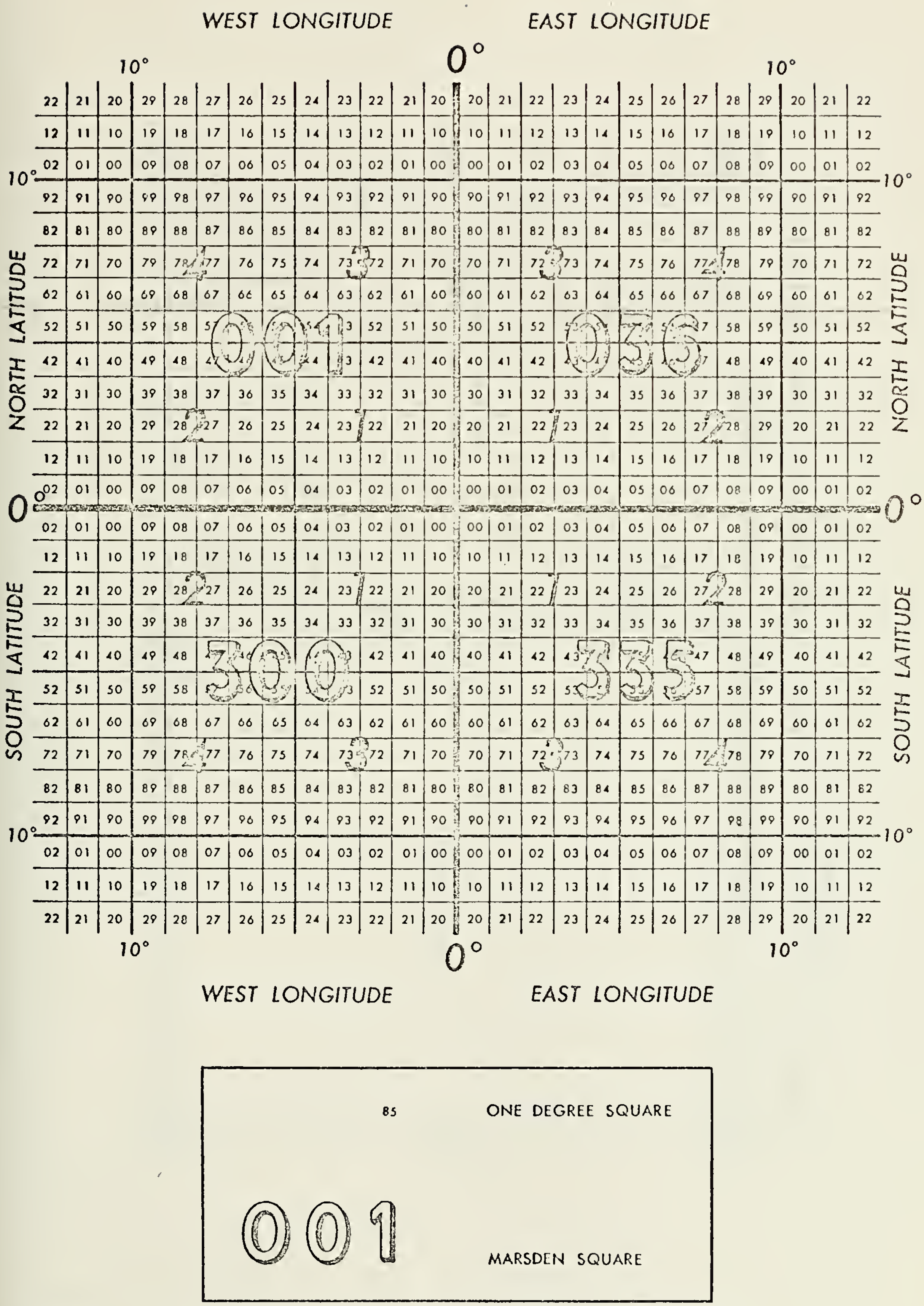

Figure 2. One degree sub-square numbering system.

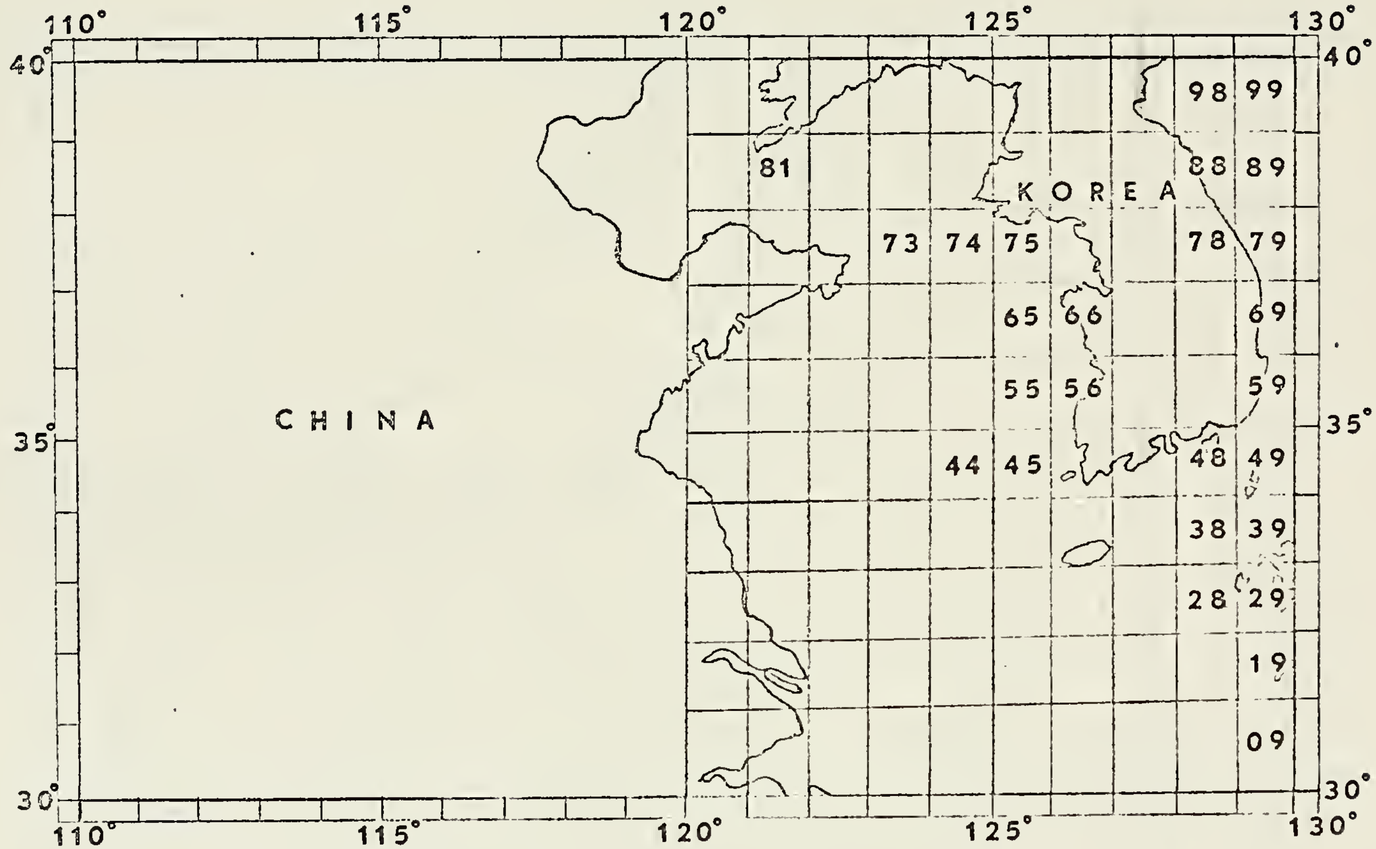

Figure 3A. One degree sub-square delineation chart for Korean waters.

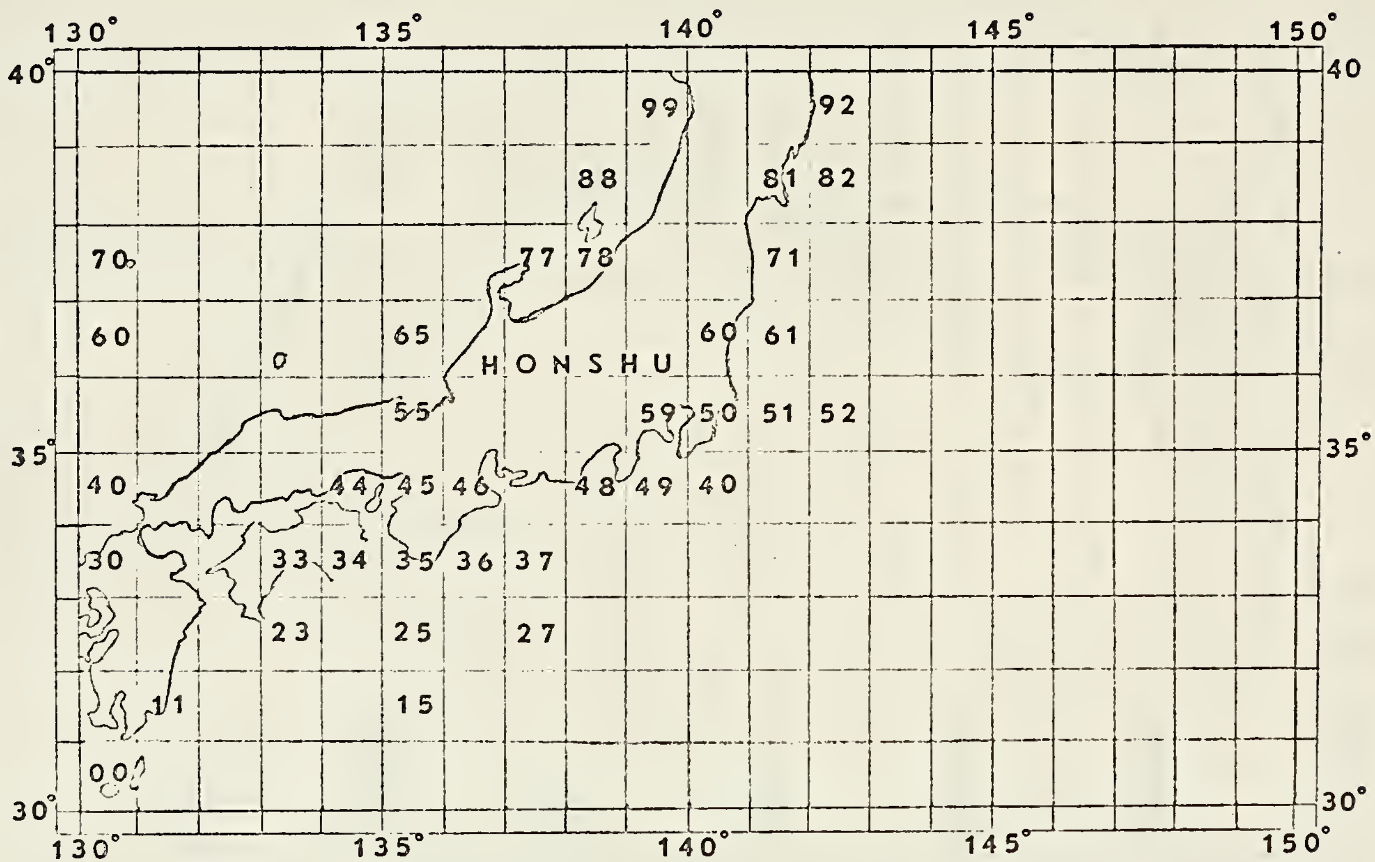

Figure 3B. One degree sub-square delineation chart for Japanese waters.

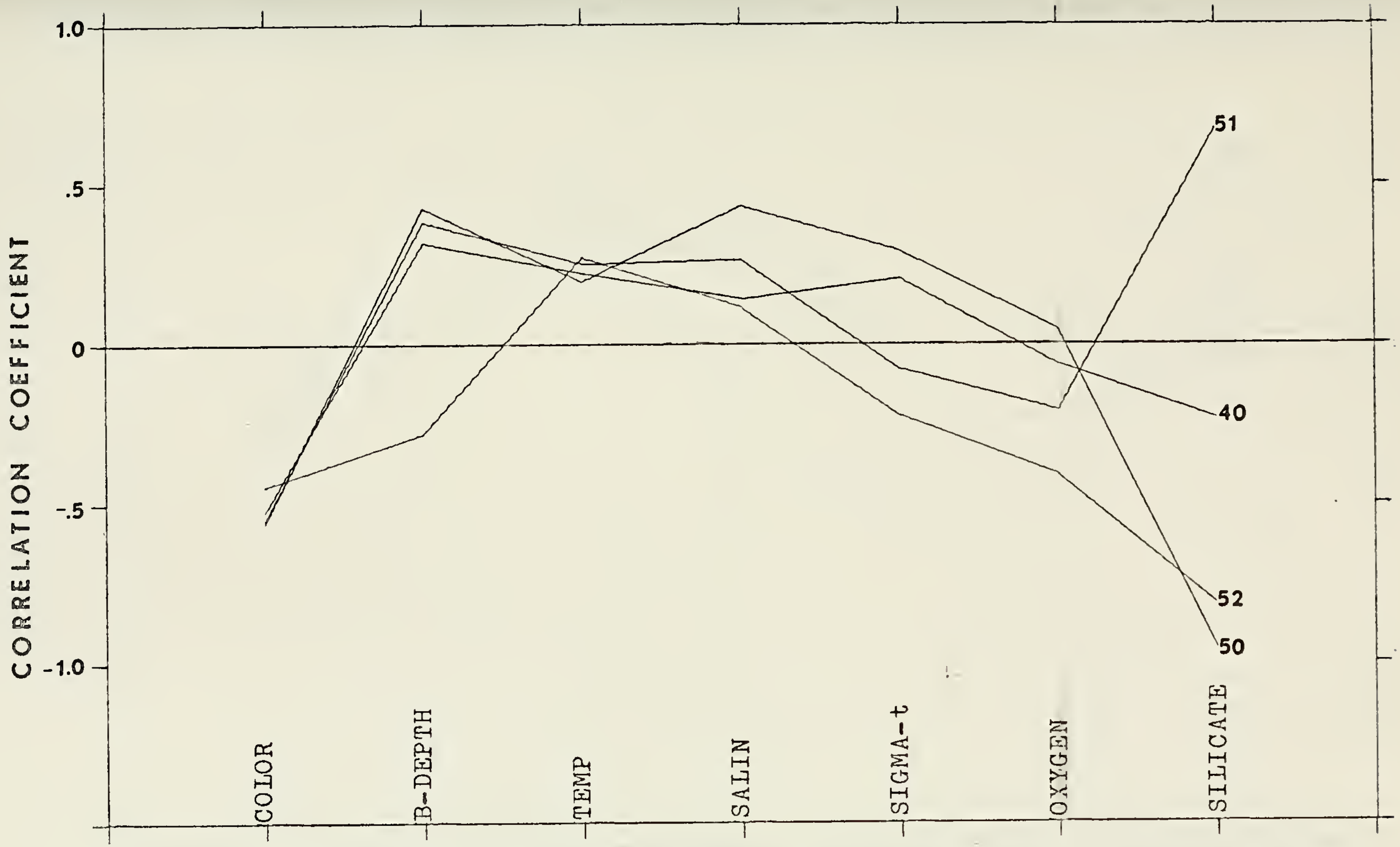

Figure 4A. Correlation coefficient graph - Western Pacific. (Marsden square 130, sub-squares 40, 50-52.)

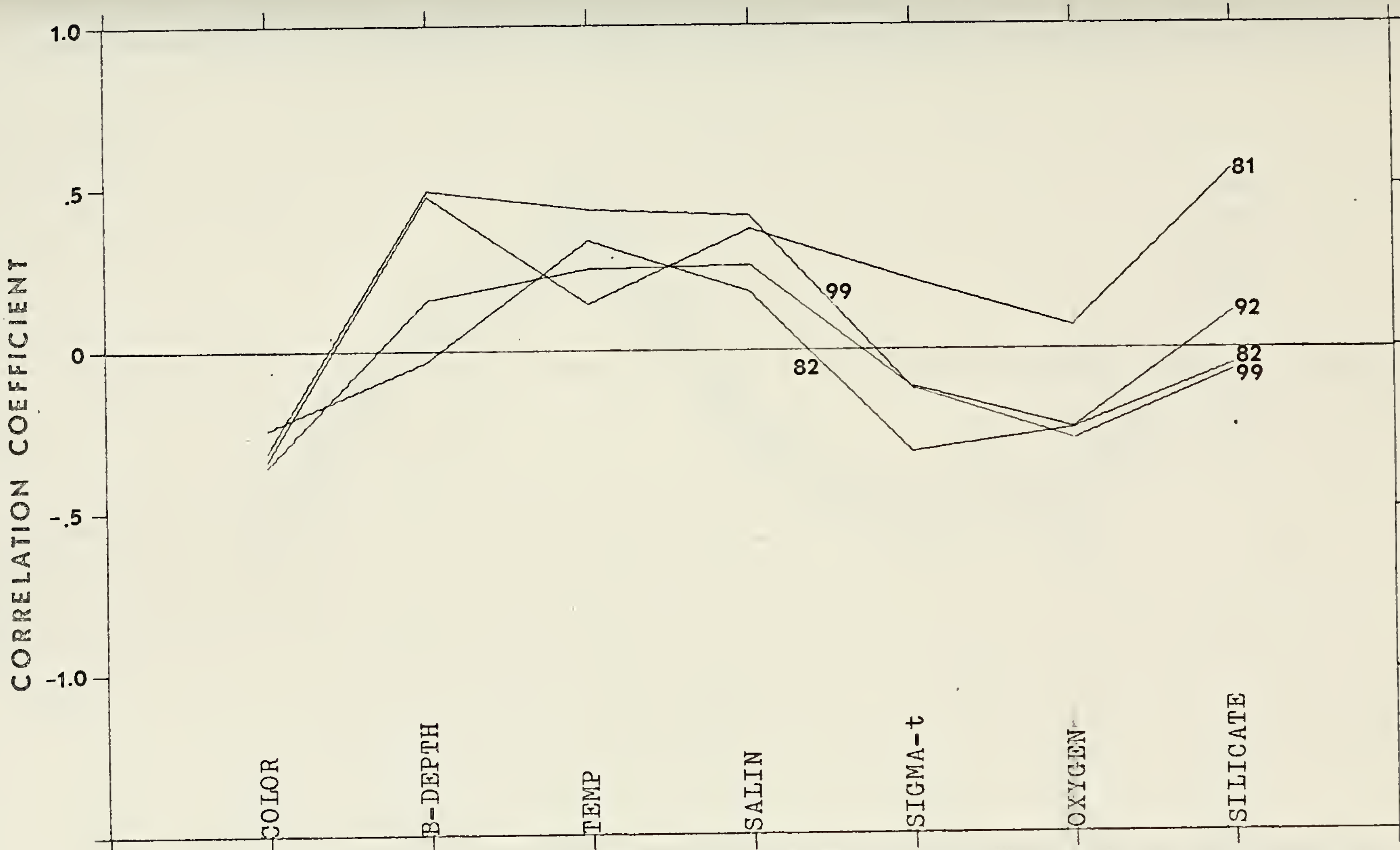

Figure 4B. Correlation coefficient graph - Western Pacific. (Marsden square 130, sub-squares 81, 82, 92 and Marsden square 131, sub-square 99.)

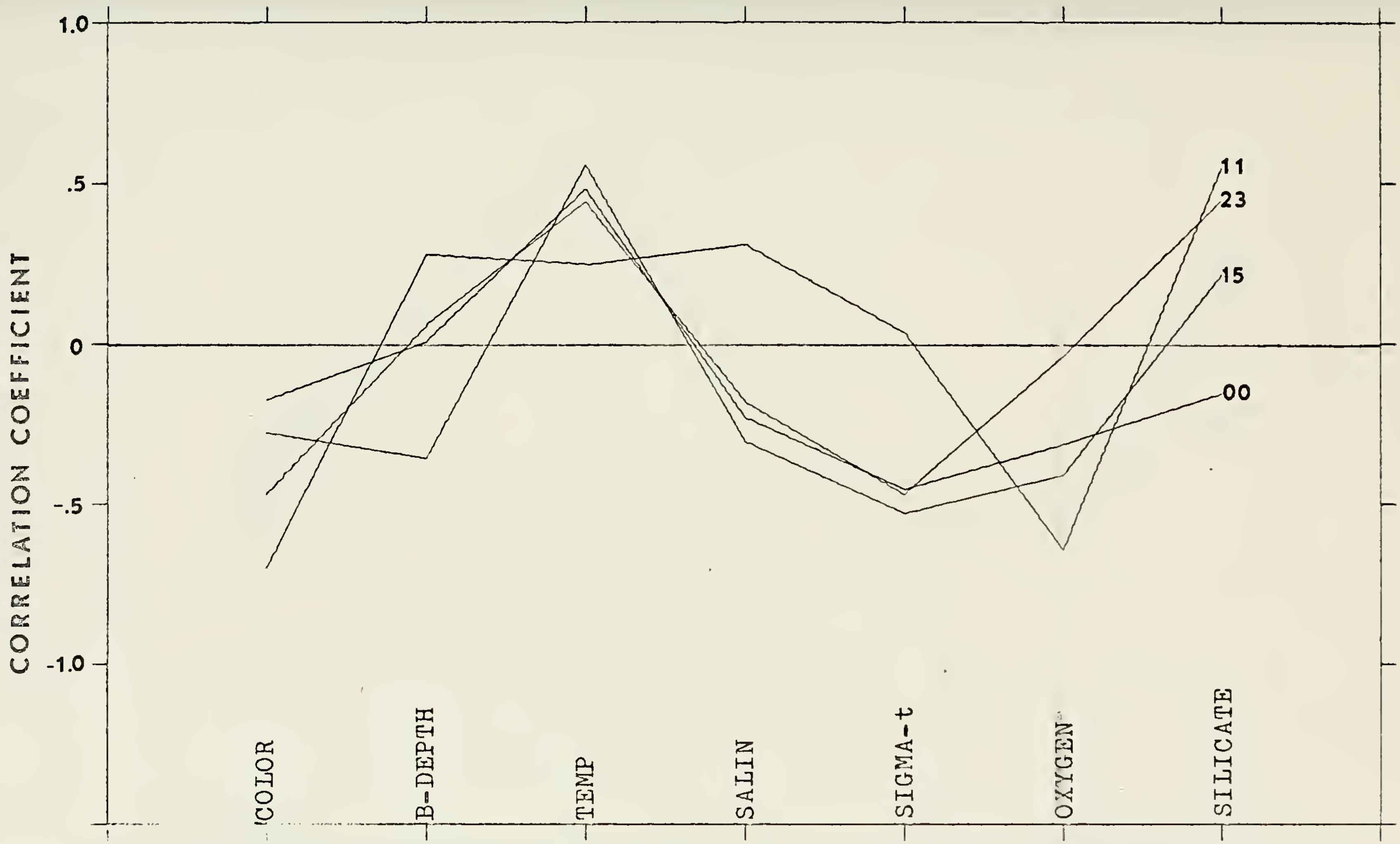

Figure 4C. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 00. 11, 15, 23.)

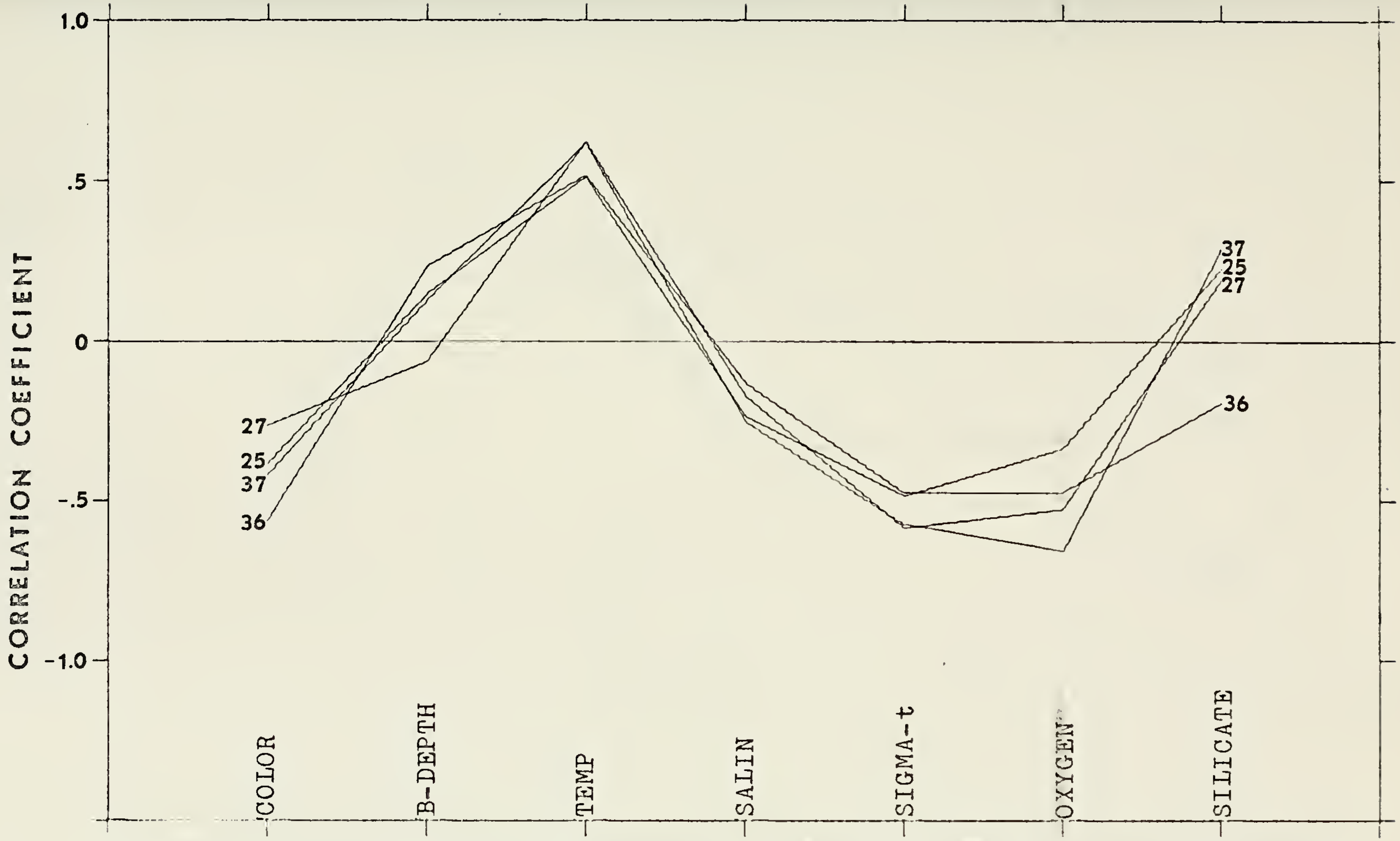

Figure 4D. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 25, 27, 36, 37.)

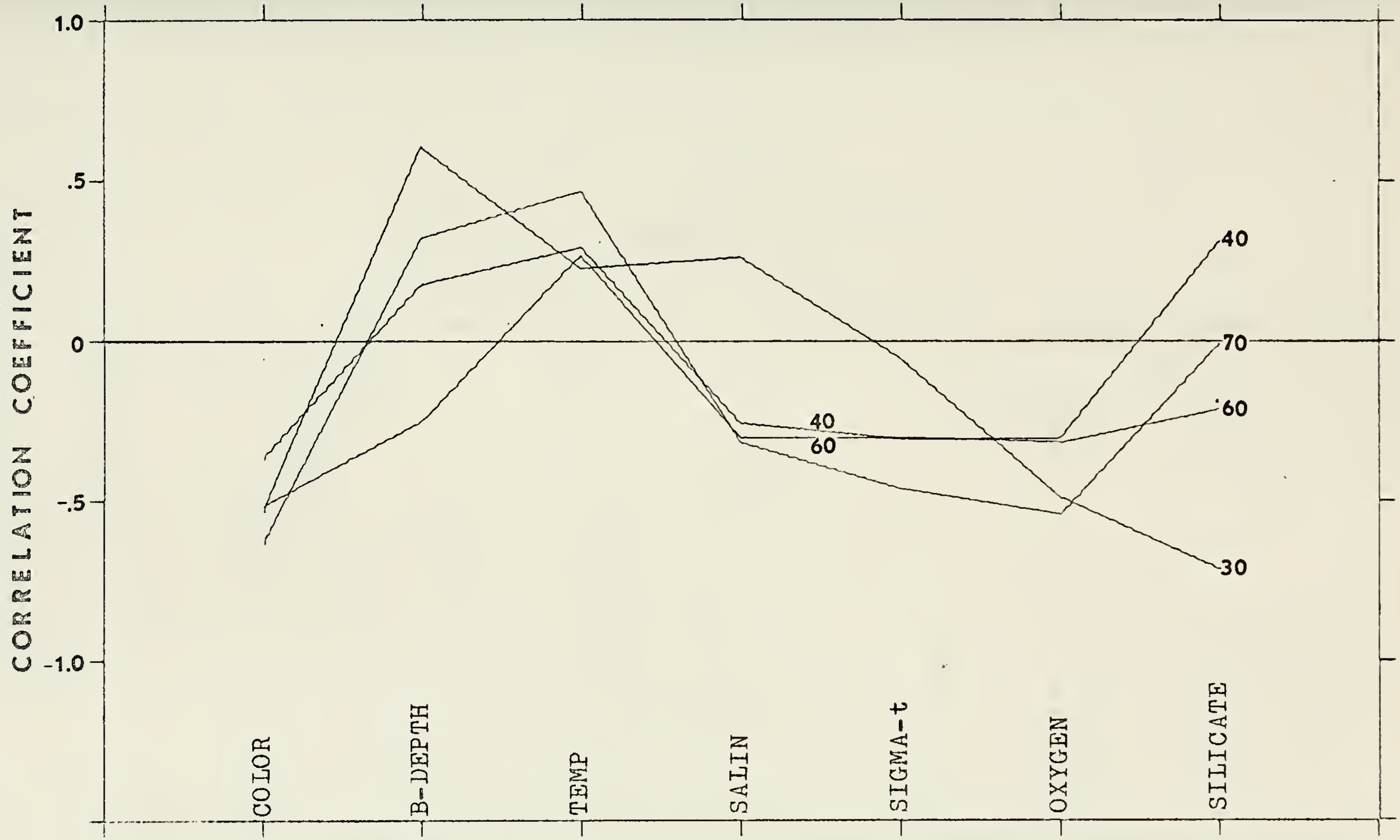

Figure 4E. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 30, 40, 60, 70.)

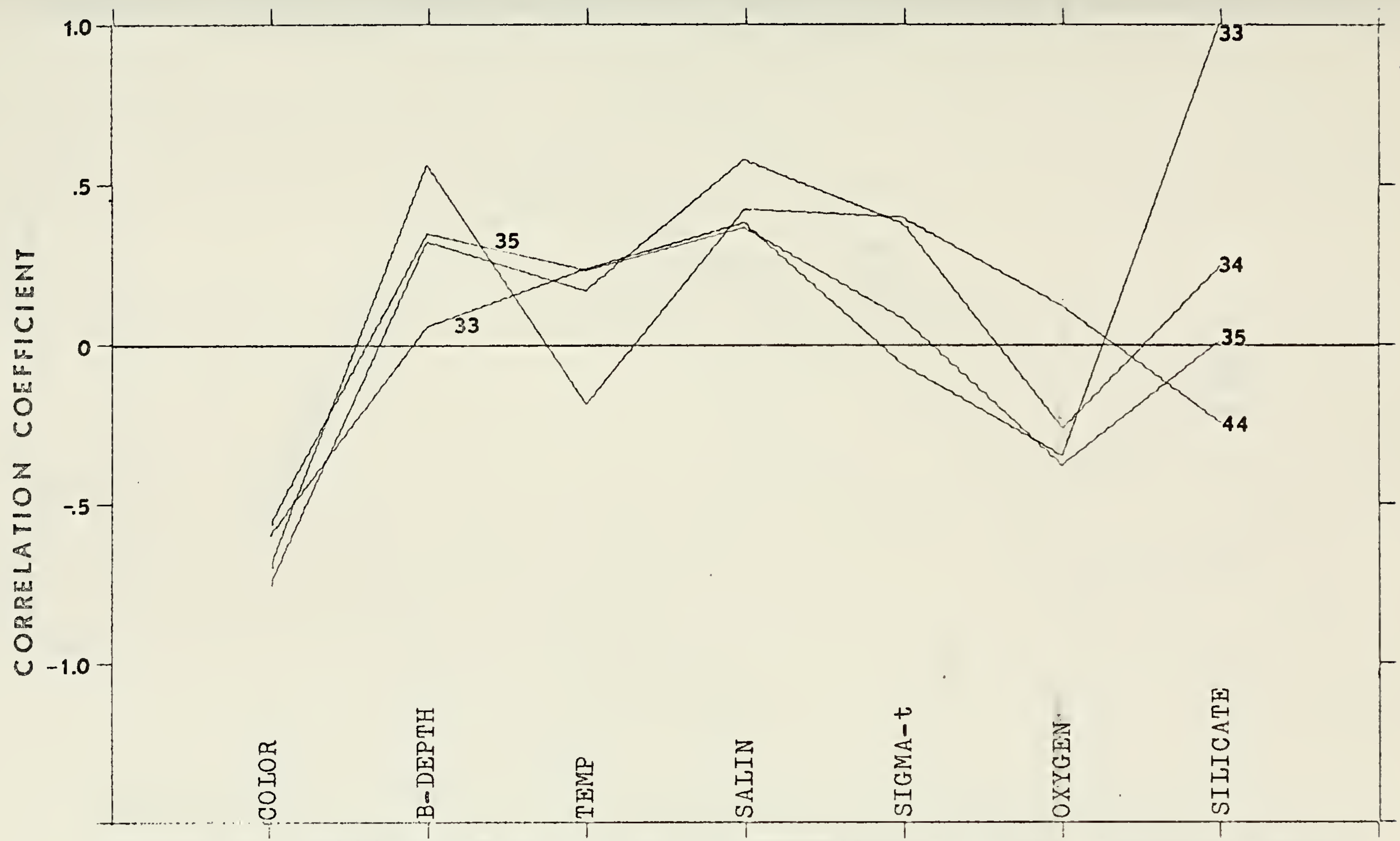

Figure 4F. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 33-35, 44.)

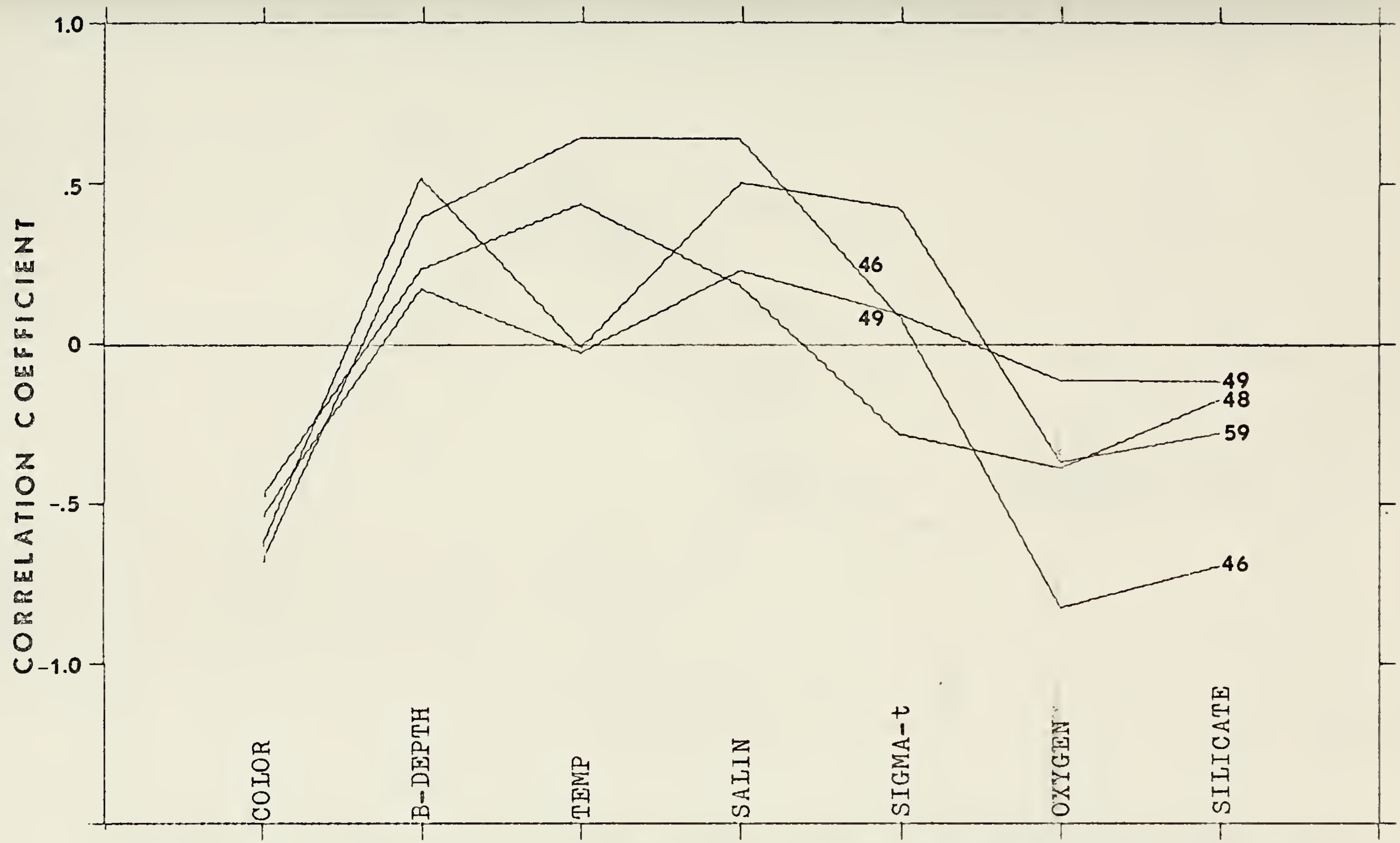

Figure 4G. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 46, 48, 49, 59.)

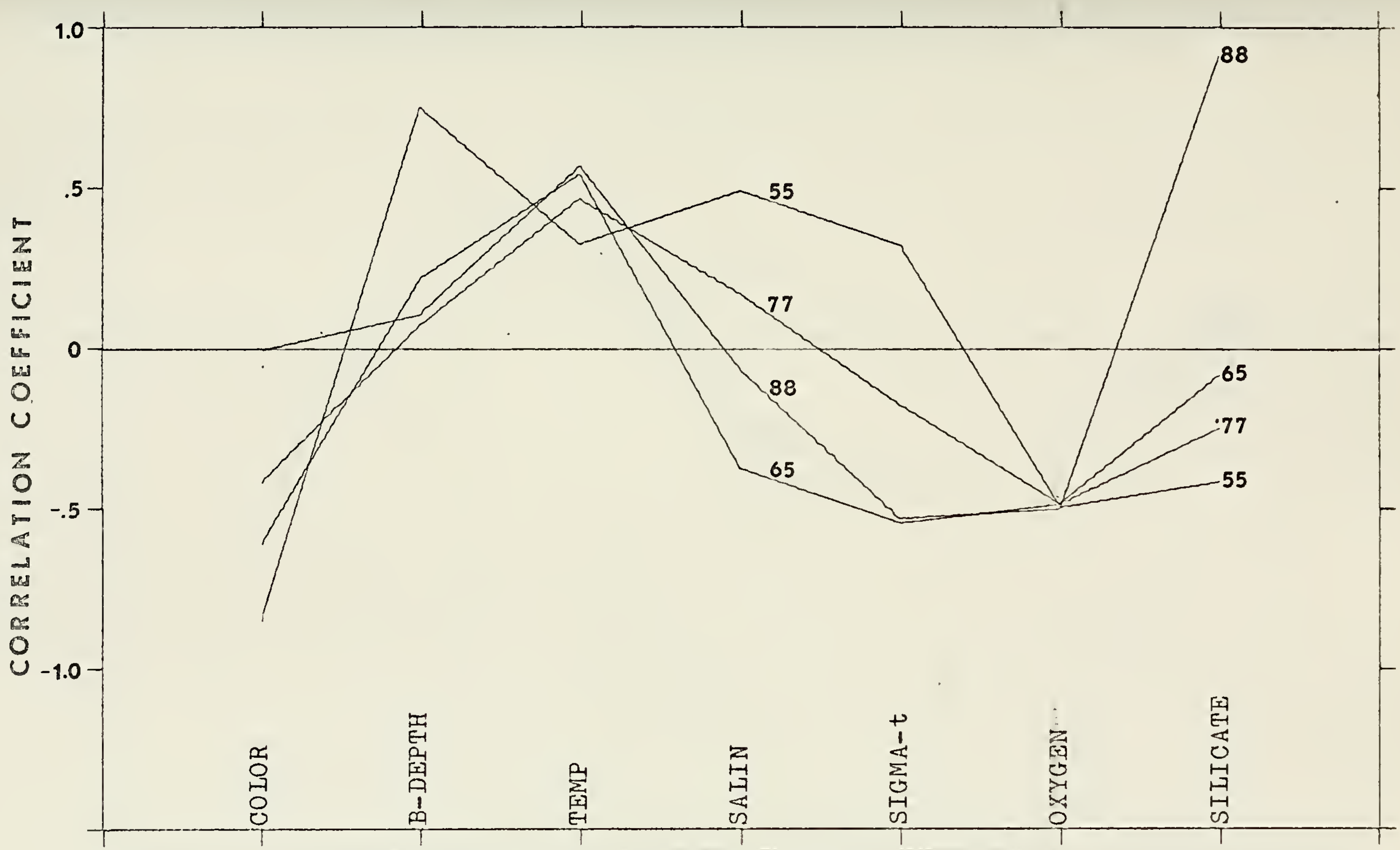

Figure 4H. Correlation coefficient graph - Western Pacific. (Marsden square 131, sub-squares 55, 65, 77, 88.)

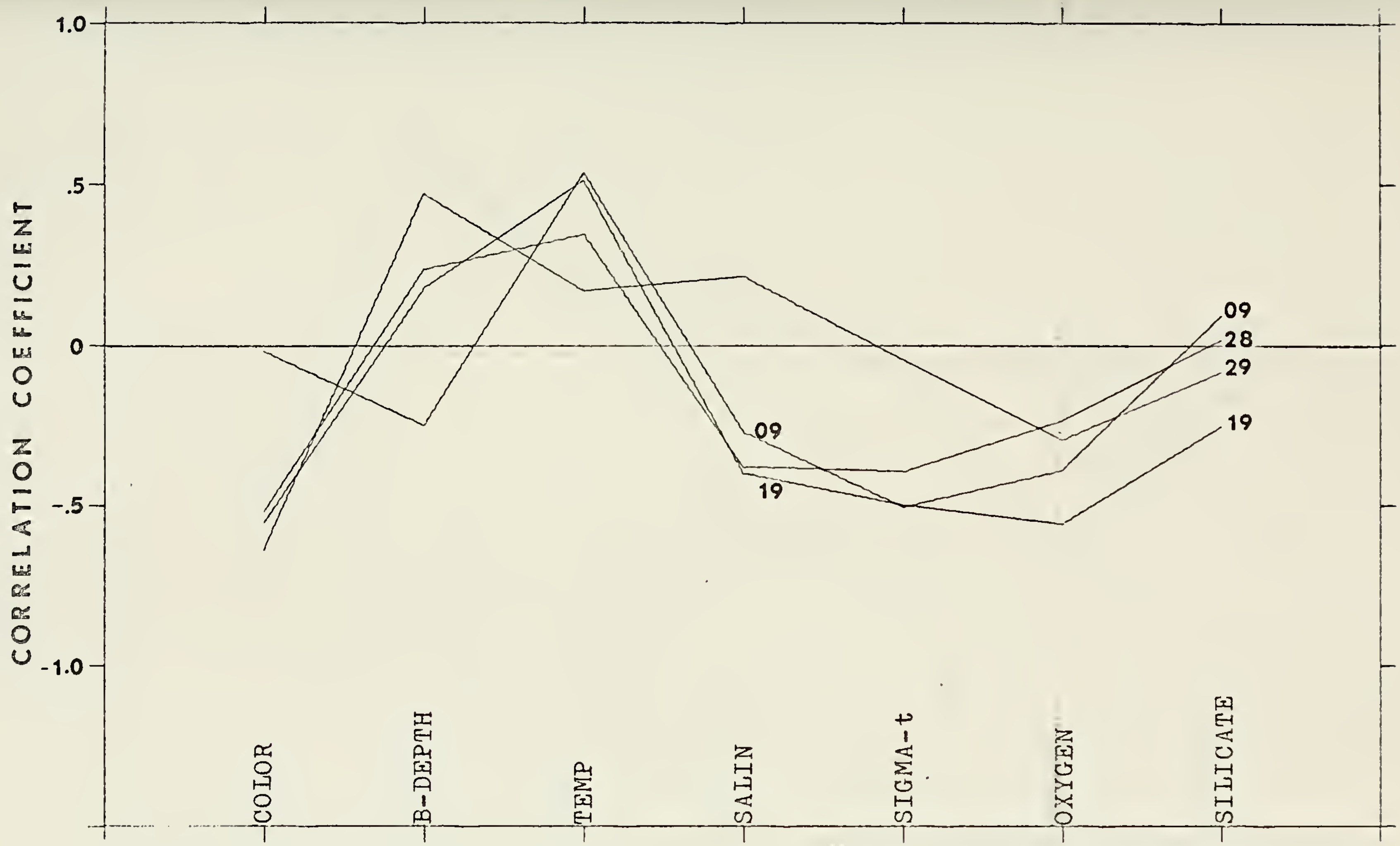

Figure 4I. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 09, 19, 28, 29.)

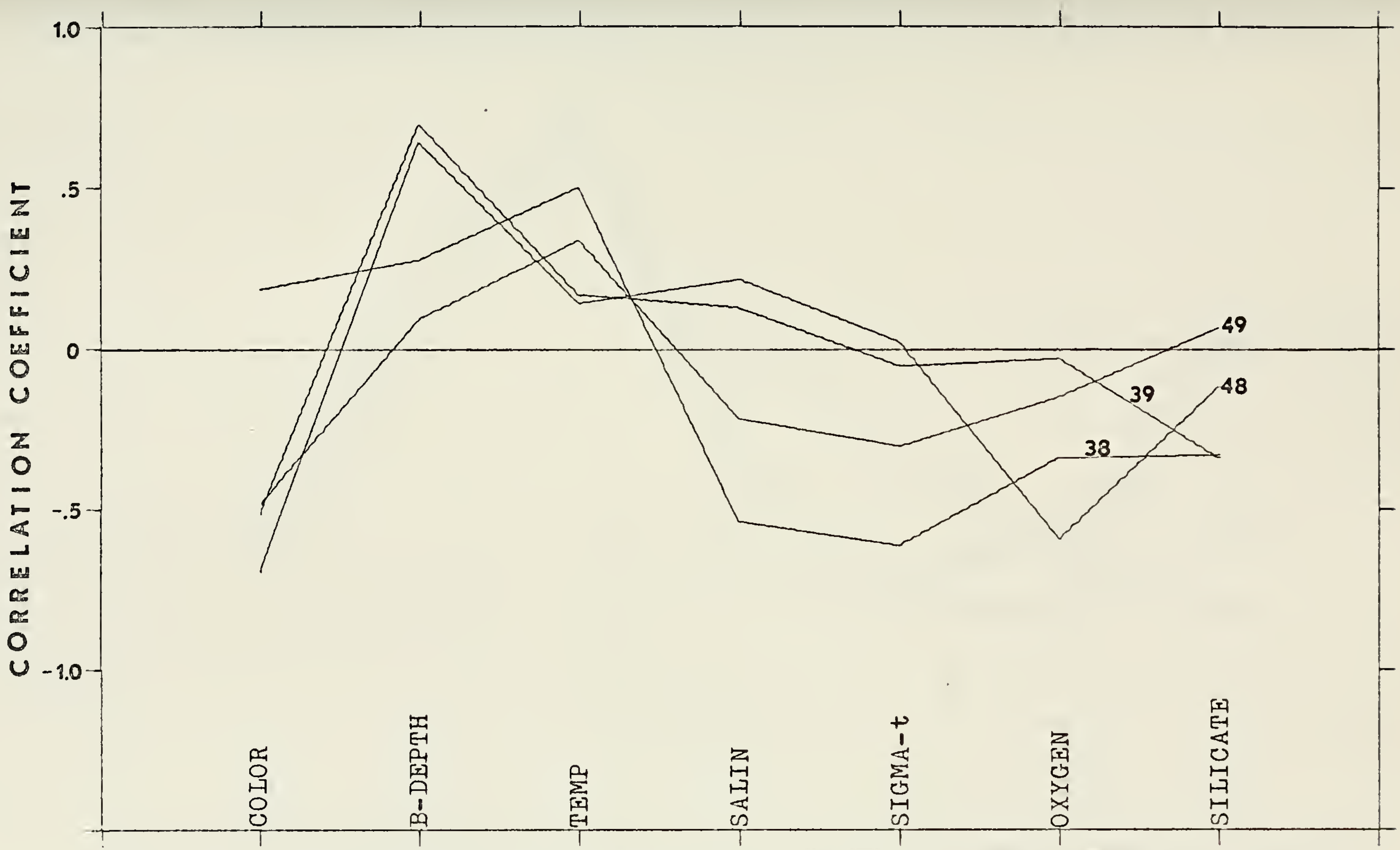

Figure 4J. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 38, 39, 48, 49.)

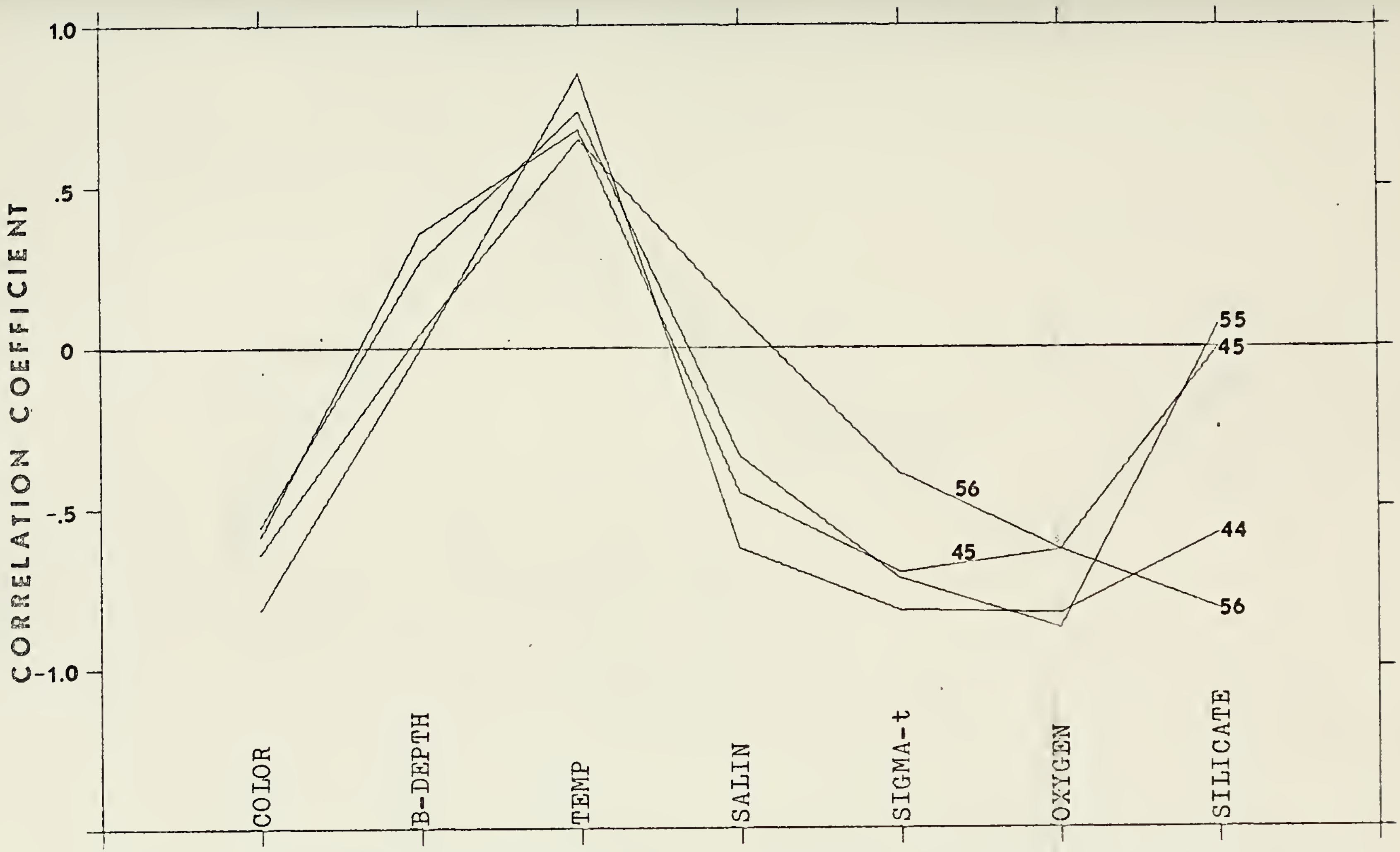

Figure 4K. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 44, 45, 55, 56.)

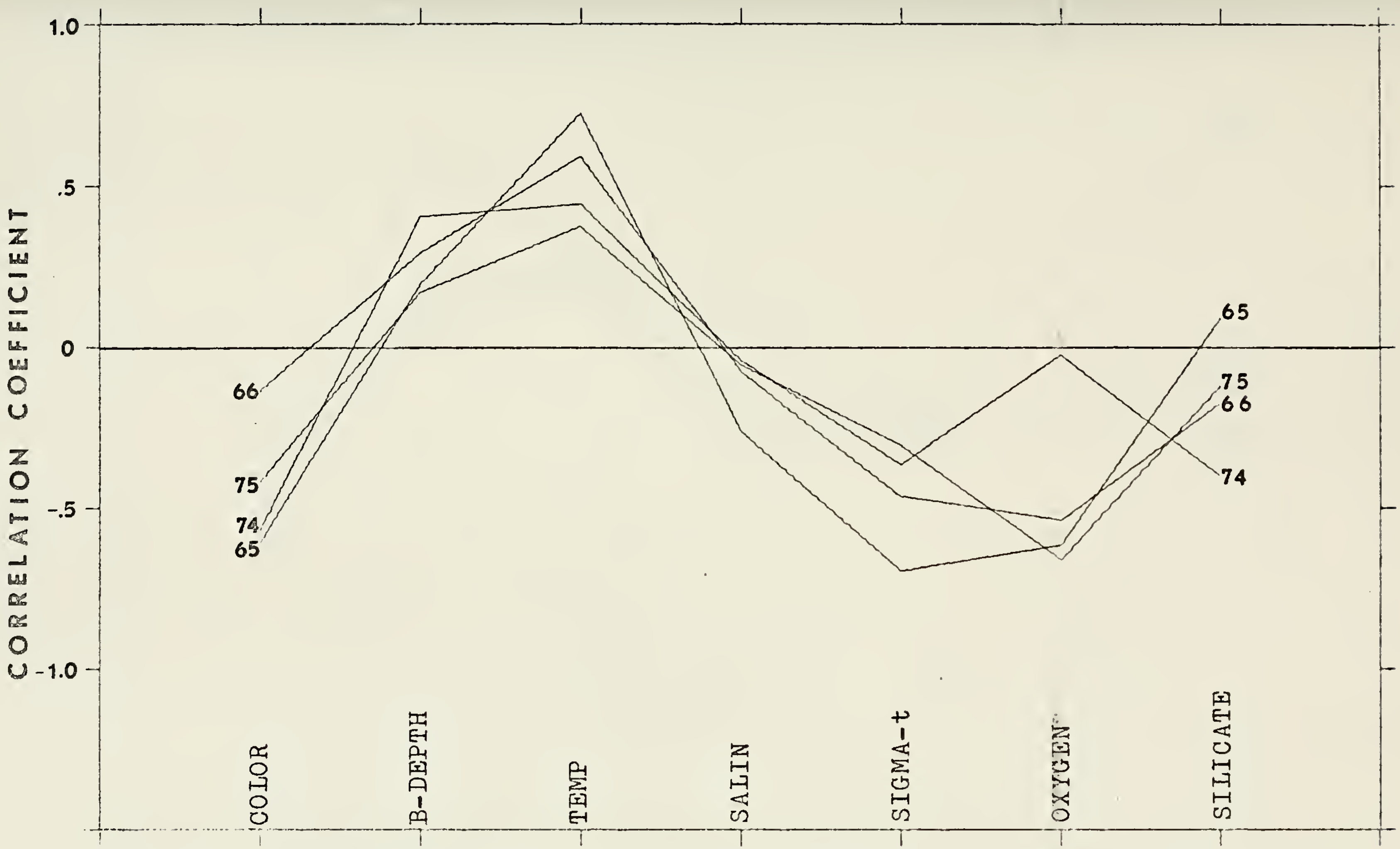

Figure 4L. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 65, 66, 74, 75.)

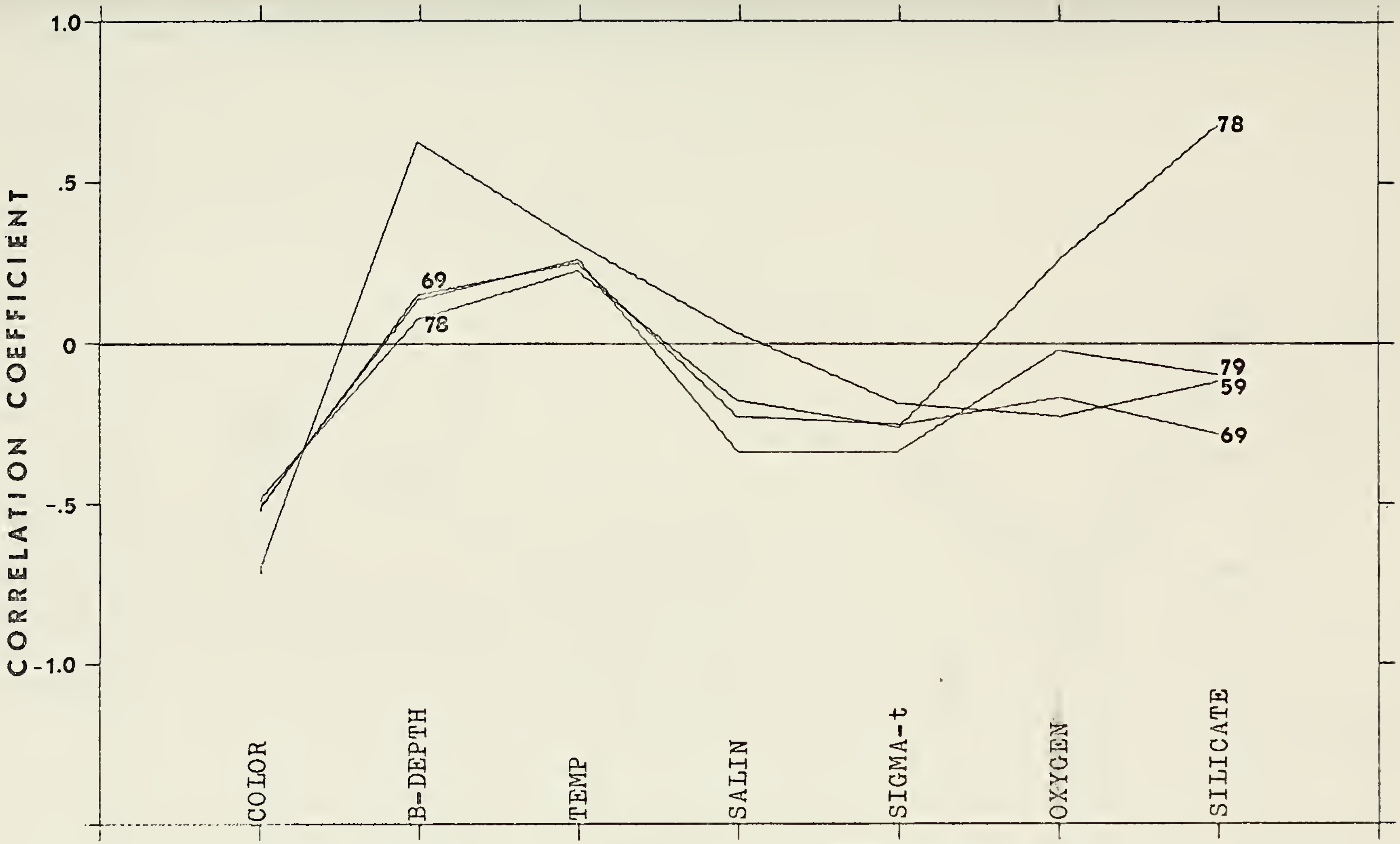

Figure 4M. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 59, 69, 78, 79.)

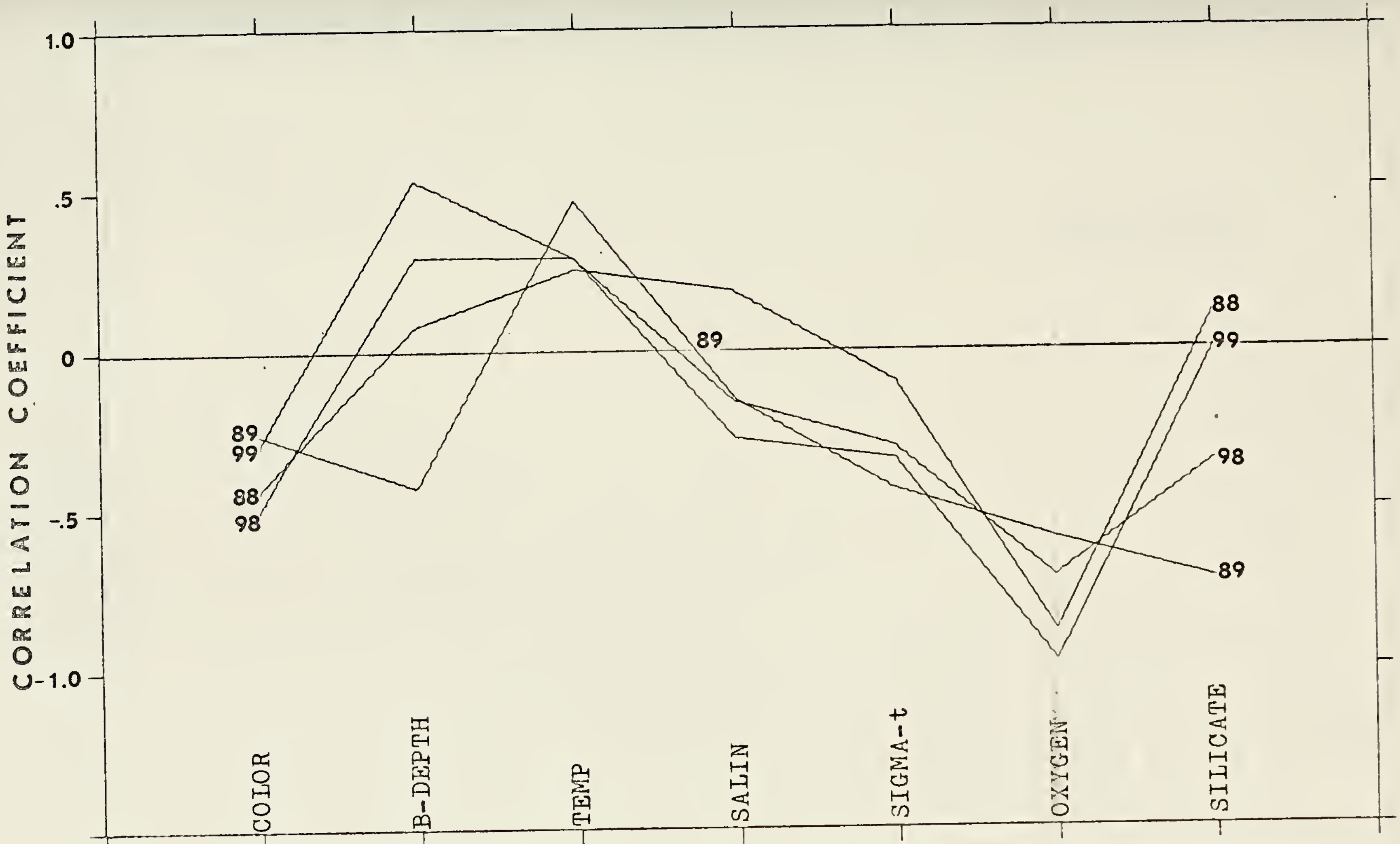

Figure 4N. Correlation coefficient graph - Western Pacific. (Marsden square 132, sub-squares 88, 89, 98, 99.)

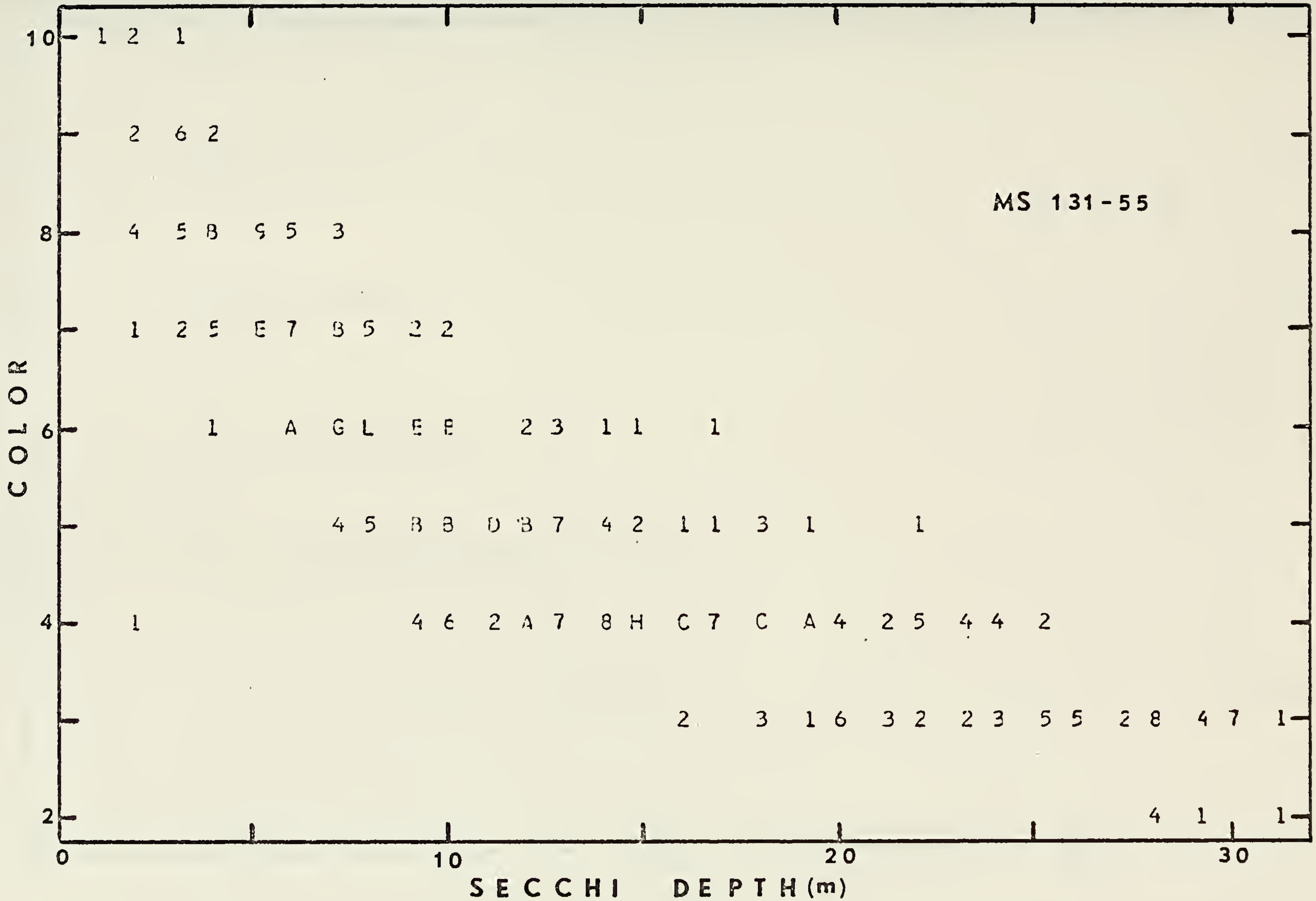

Figure 5. Color plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

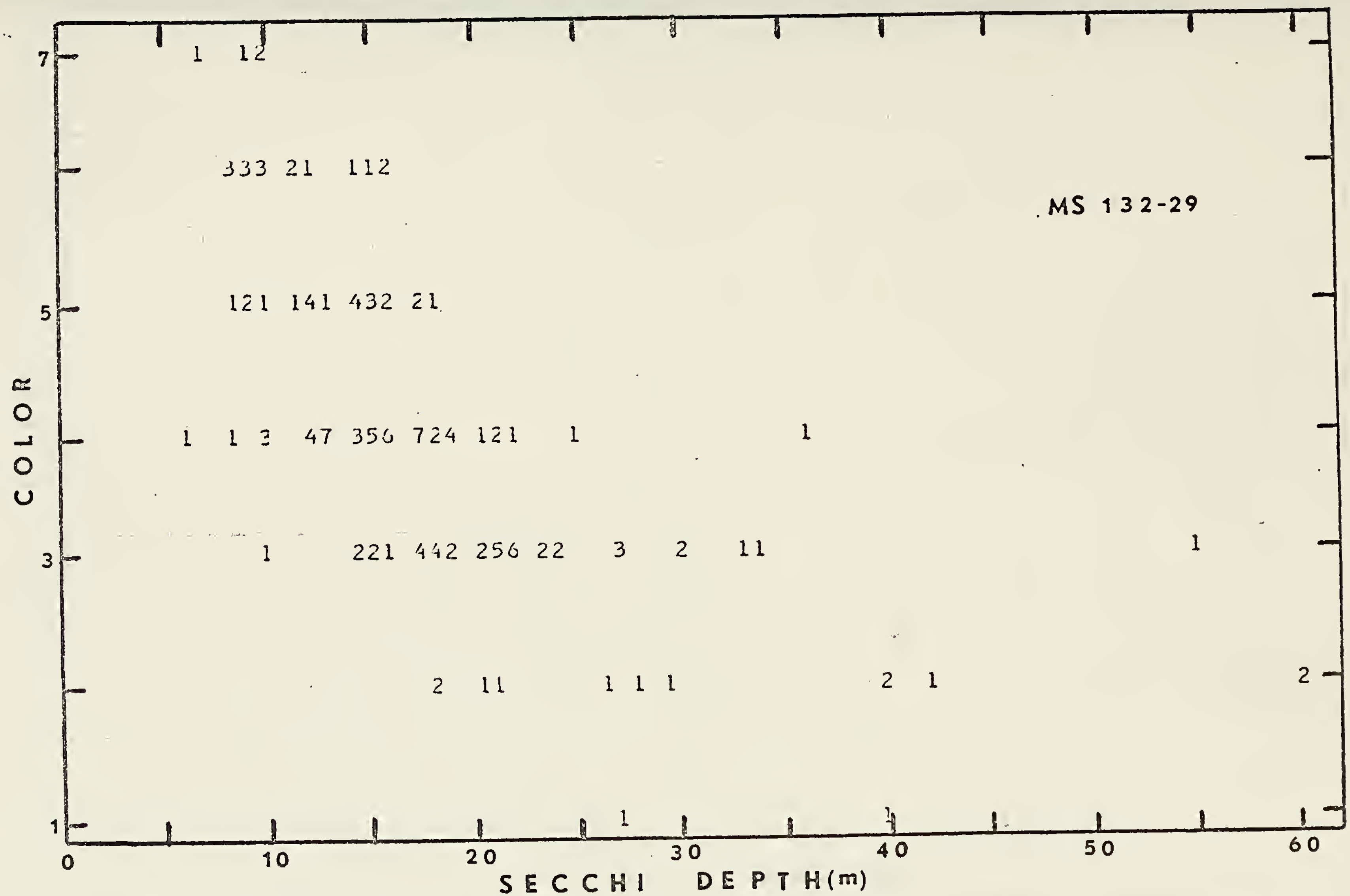

Figure 6. Color plotted as a function of Secchi depth. (Marsden square 132-29. Refer to Table IV for point density code.)

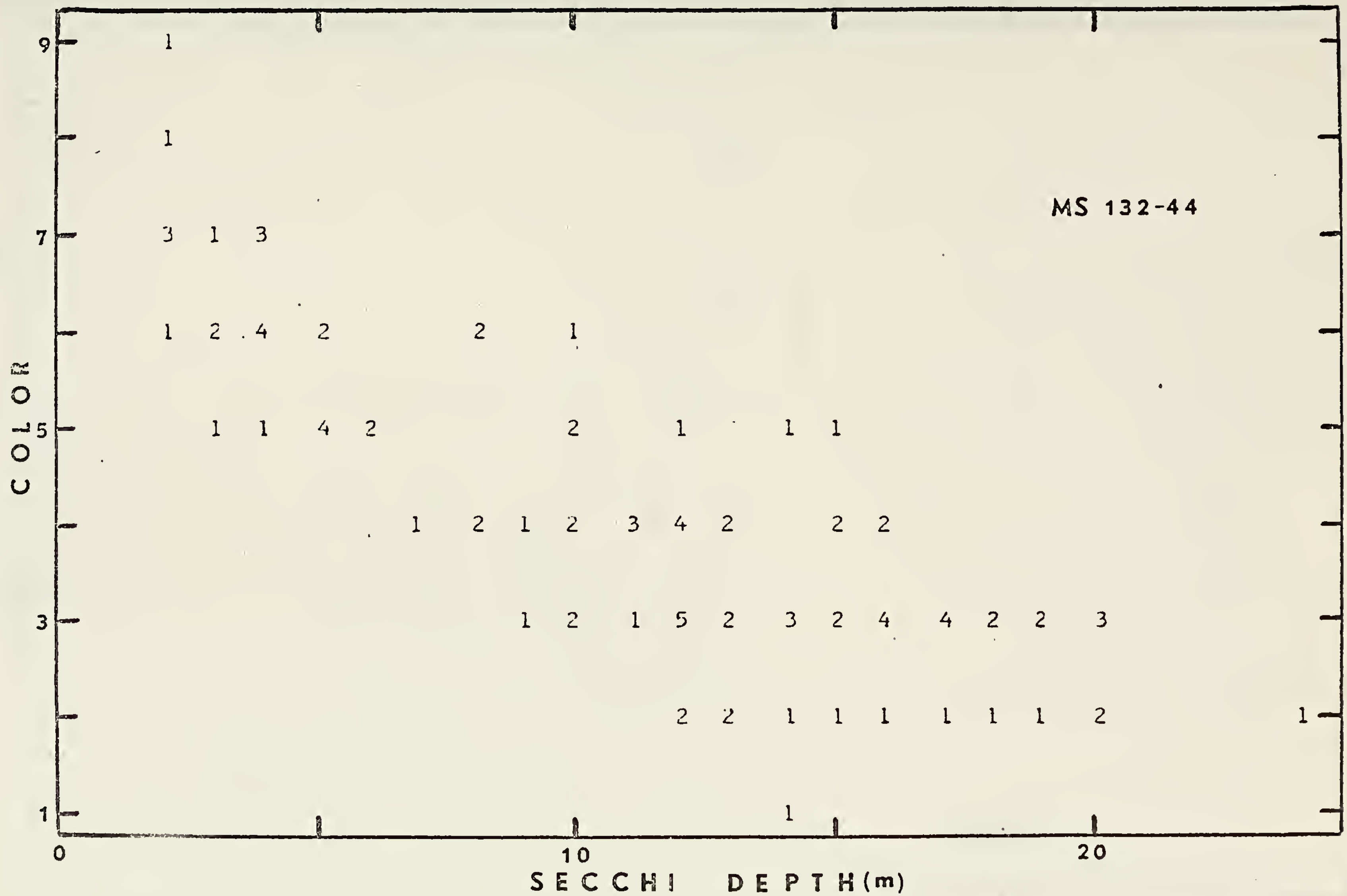

Figure 7. Color plotted as a function of Secchi depth. (Marsden square 132-44. Refer to Table IV for point density code.)

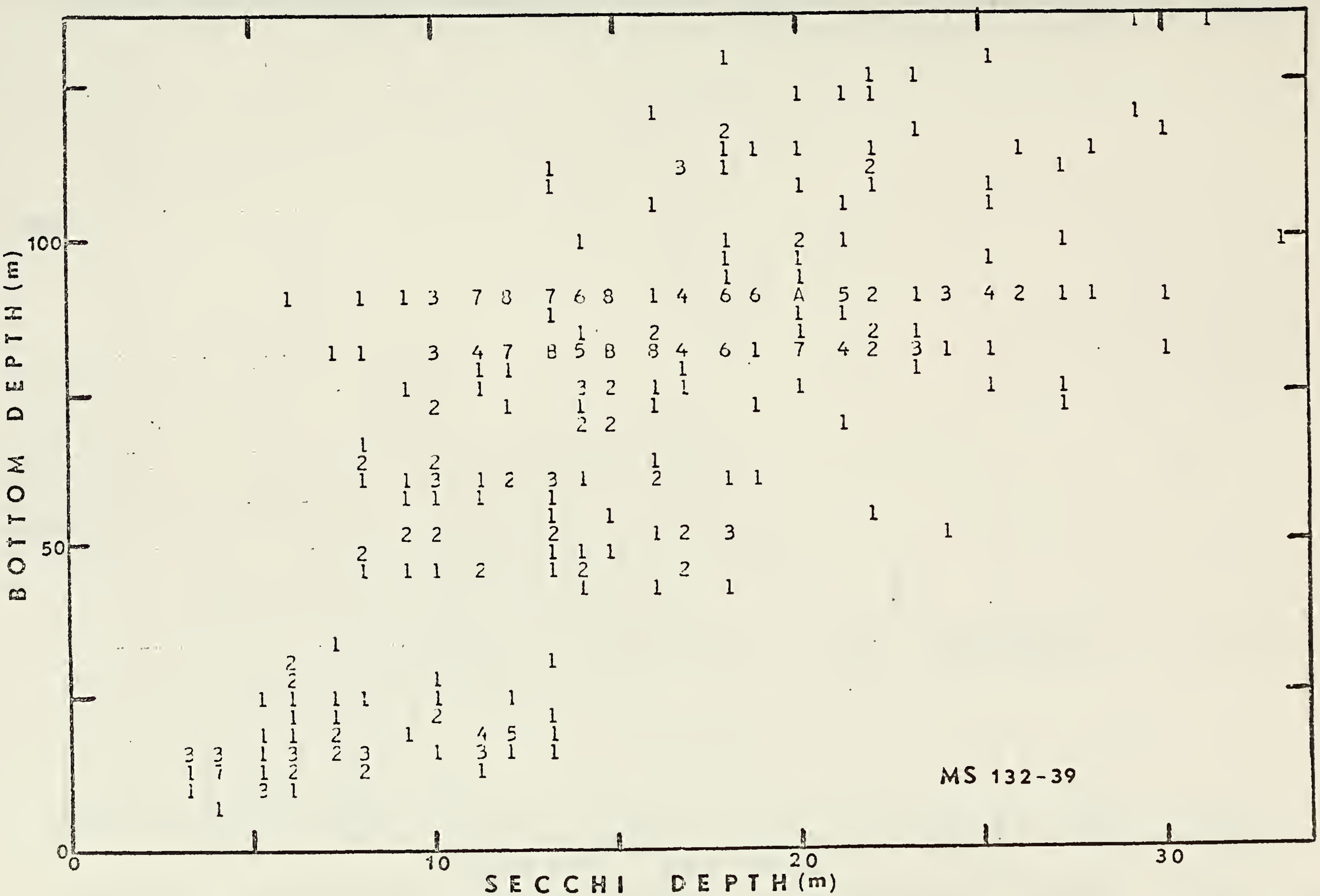

Figure 8. Bottom depth plotted as a function of Secchi depth. (Marsden square 132-39. Refer to Table IV for point density code.)

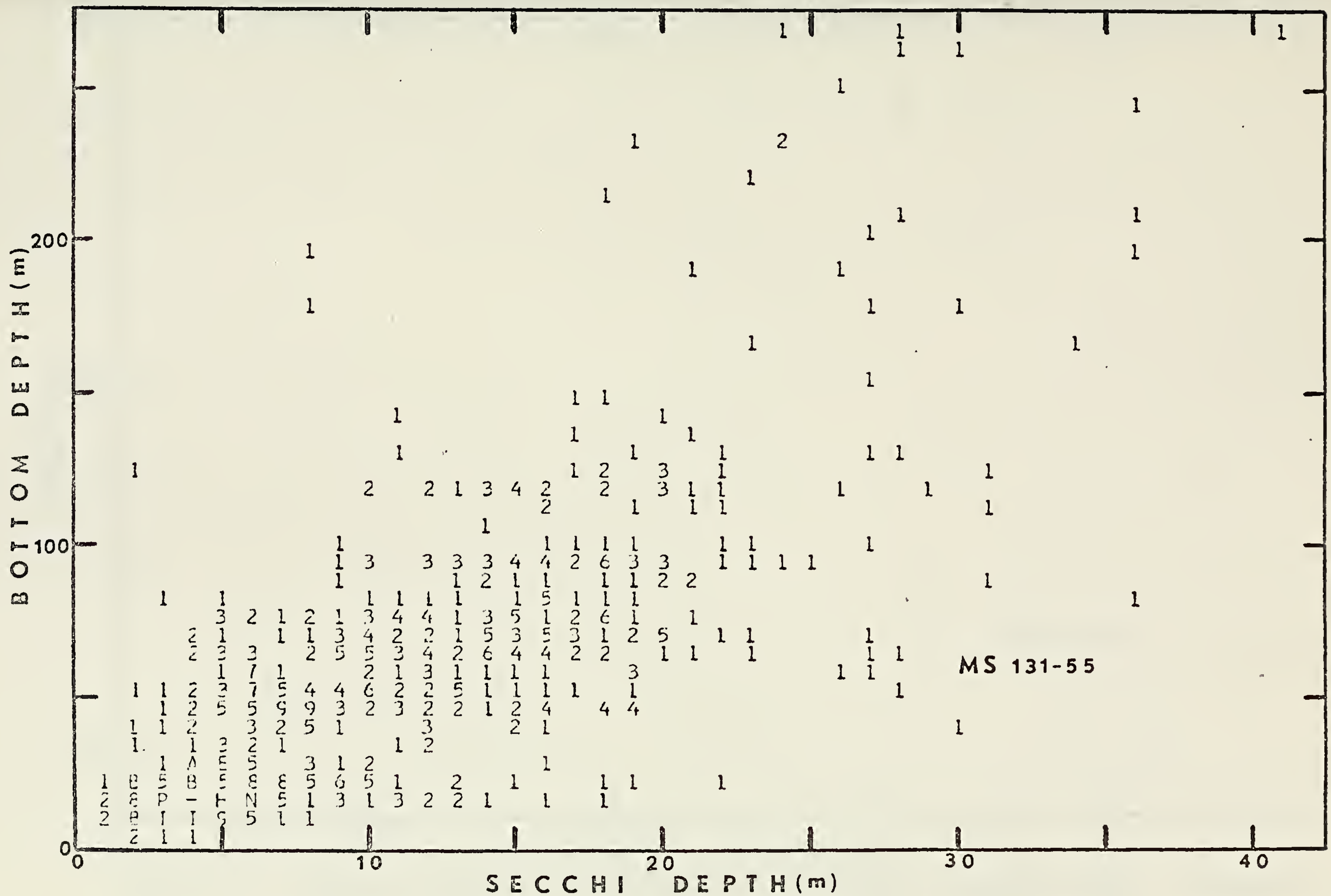

Figure 9. Bottom depth plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

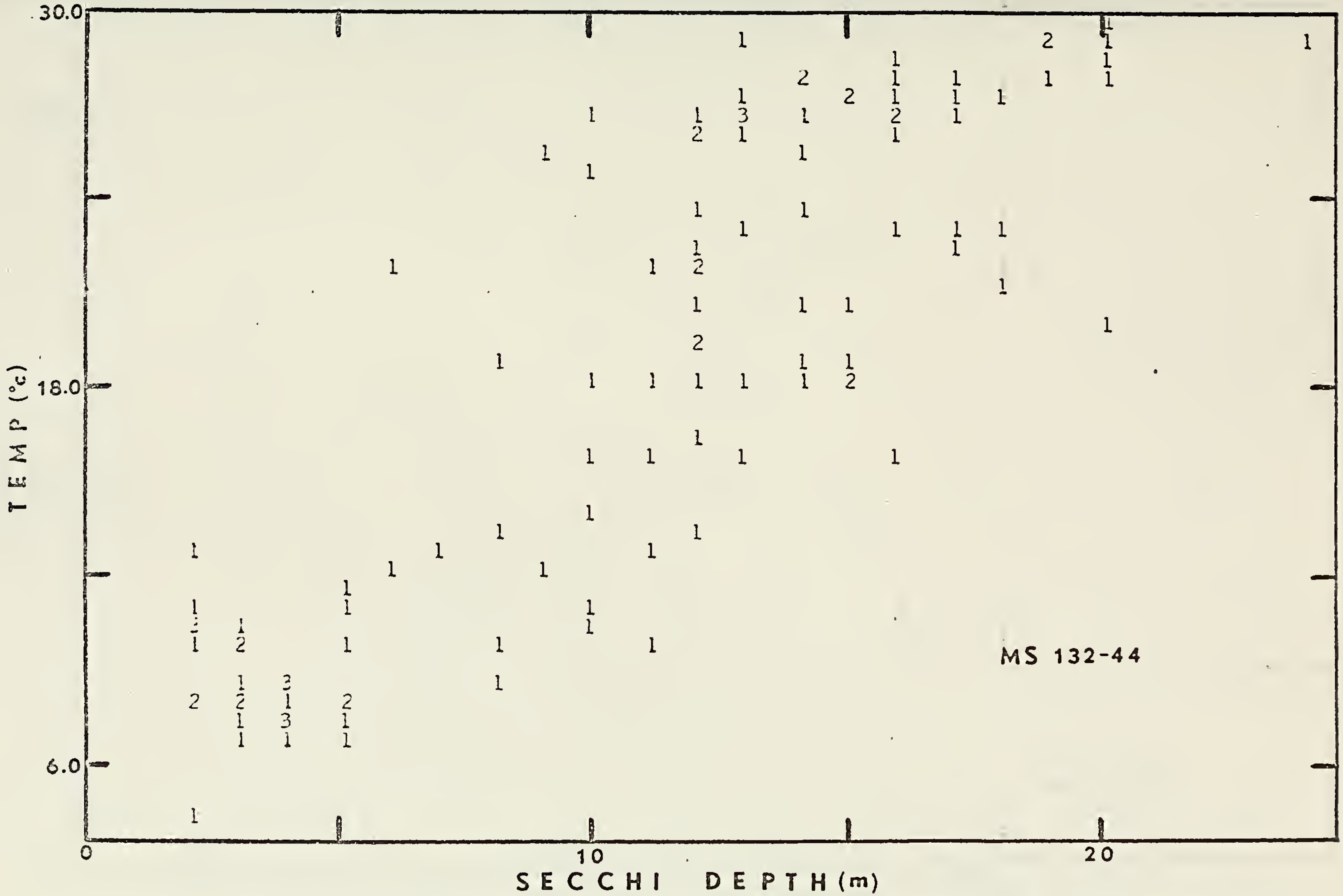

Figure 10. Surface temperature plotted as a function of Secchi depth. (Marsden square 132-44. Refer to Table IV for point density code.)

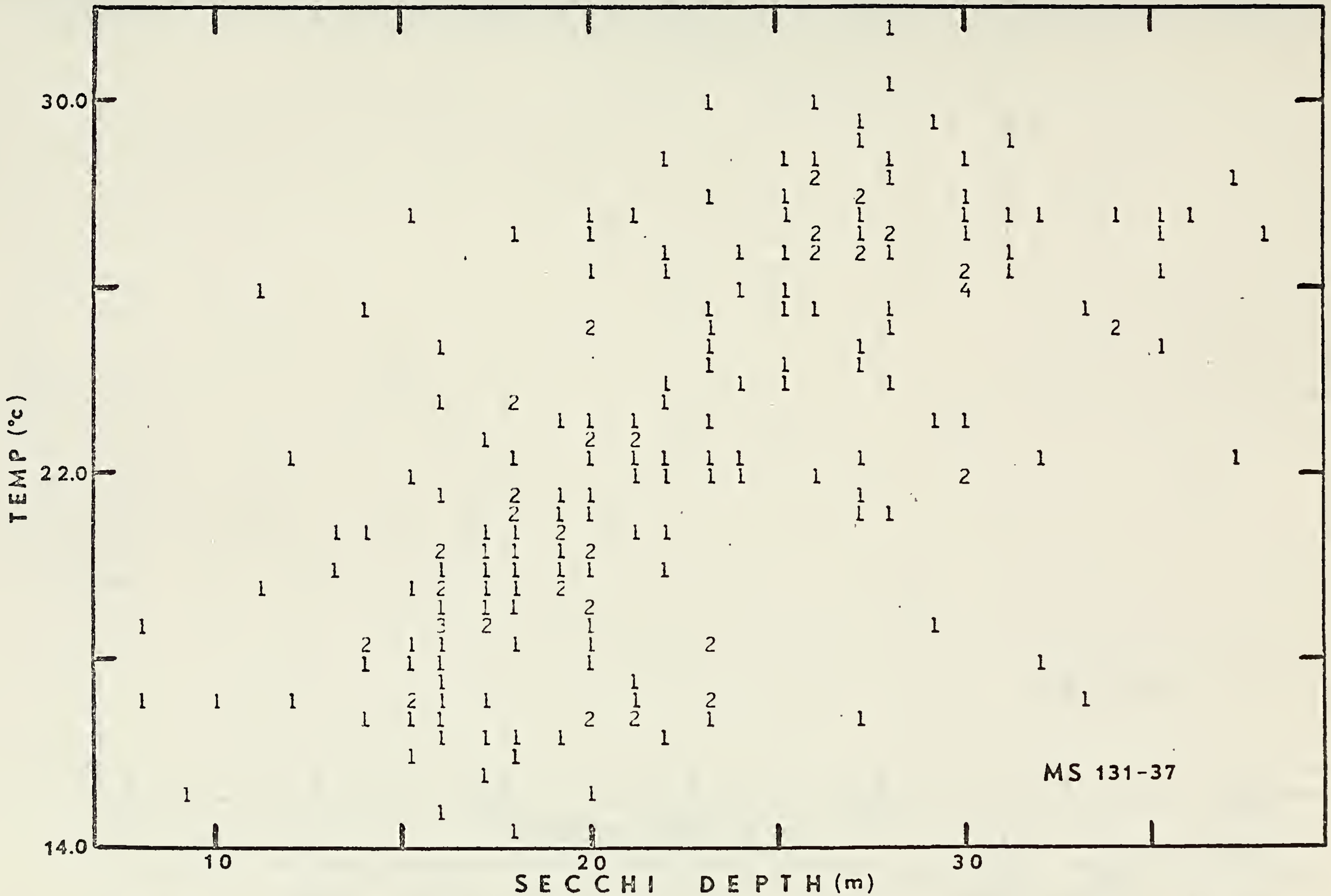

Figure 11. Surface temperature plotted as a function of Secchi depth. (Marsden square 131-37. Refer to Table IV for point density code.)

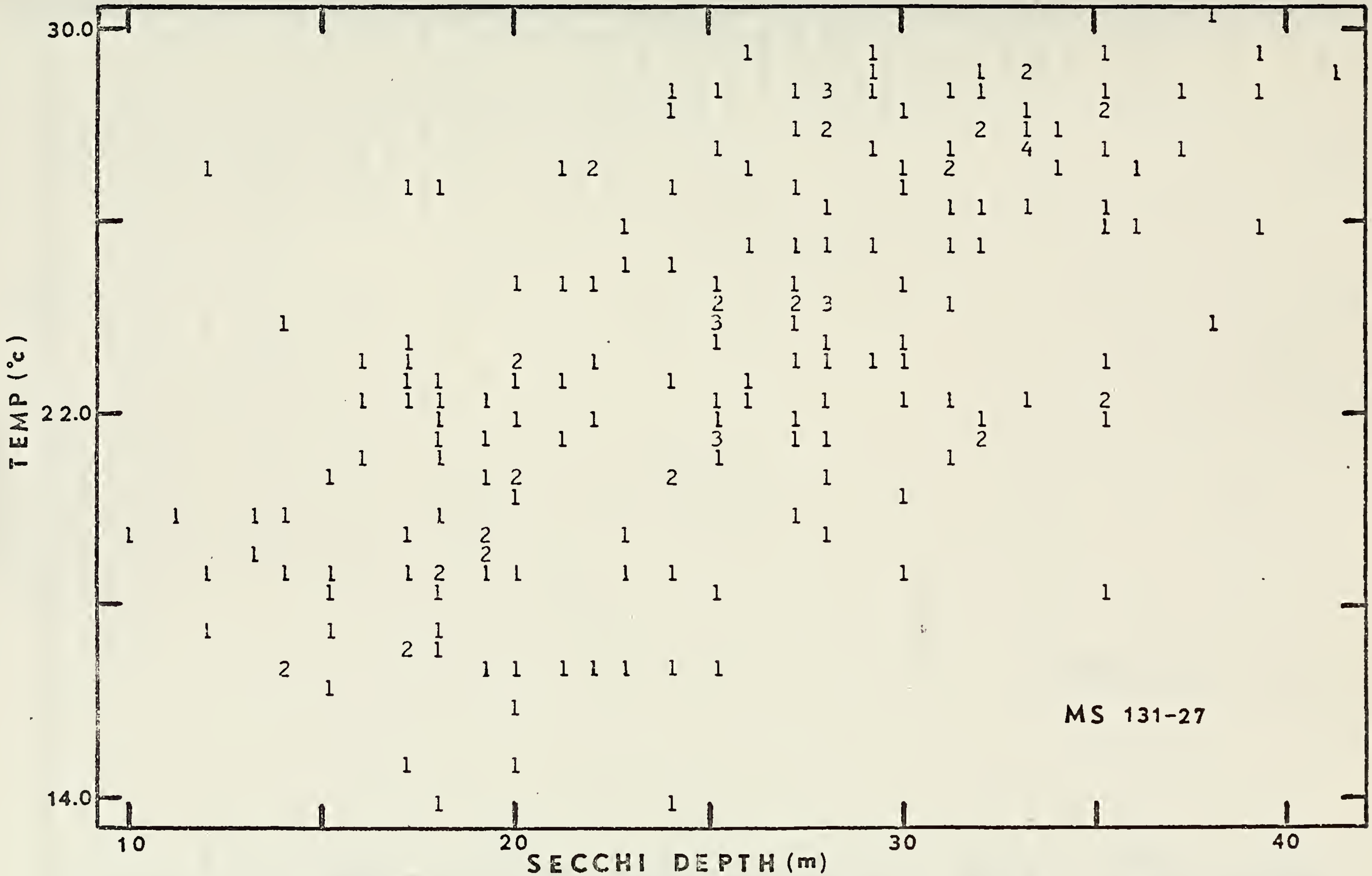

Figure 12. Surface temperature plotted as a function of Secchi depth. (Marsden square 131-27. Refer to Table IV for point density code.)

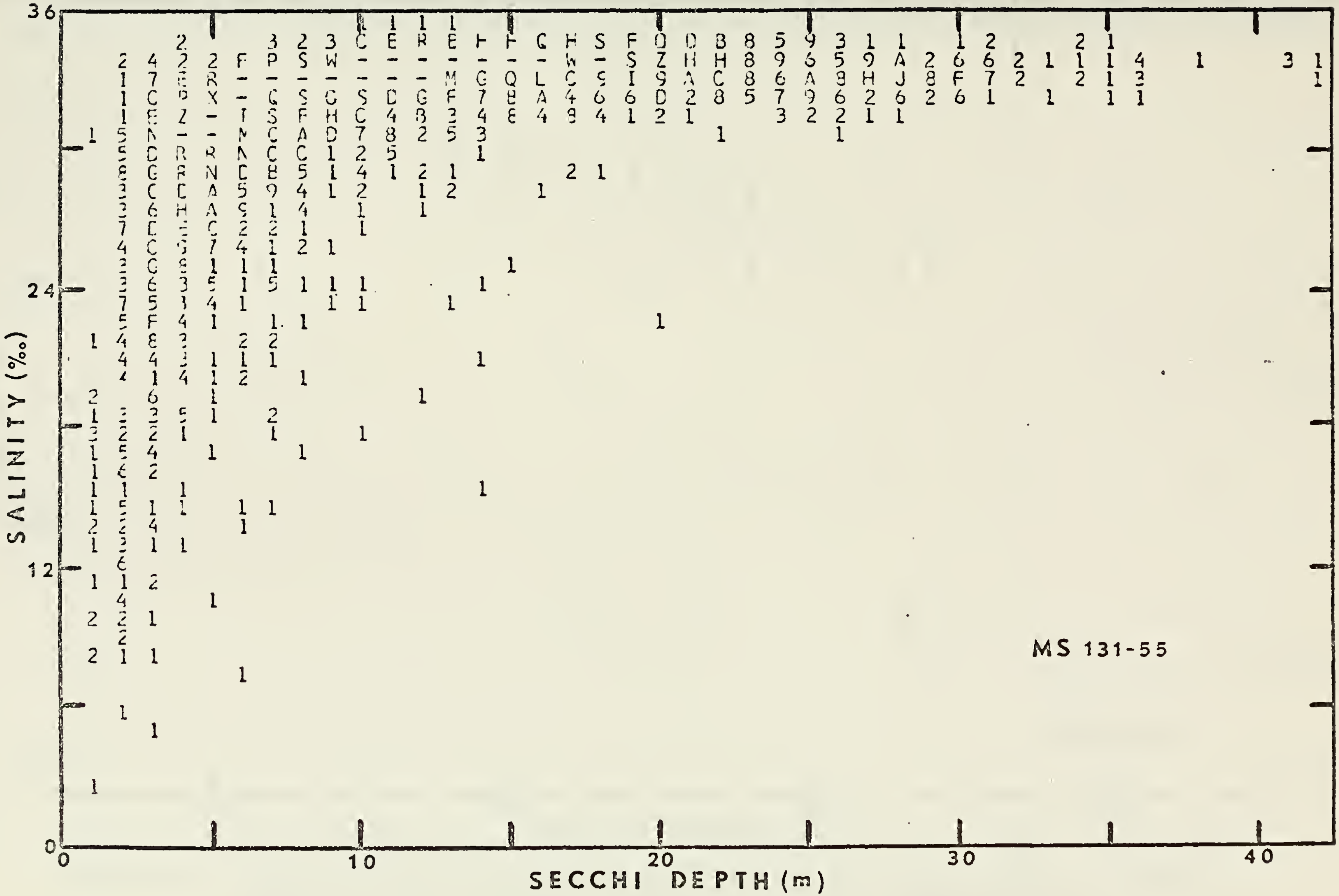

Figure 13. Surface salinity plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

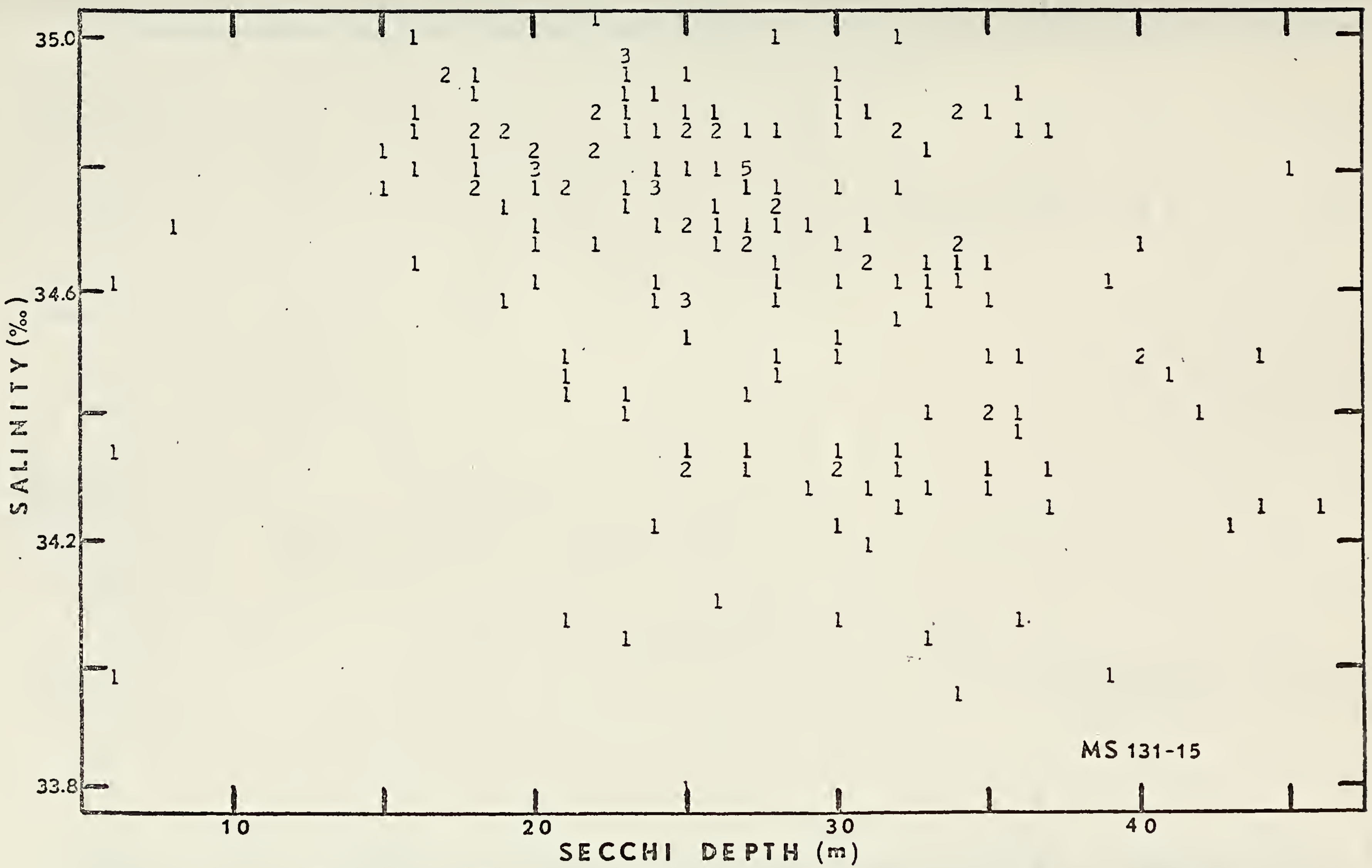

Figure 14. Surface salinity plotted as a function of Secchi depth. (Marsden square 131-15. Refer to Table IV for point density code.)

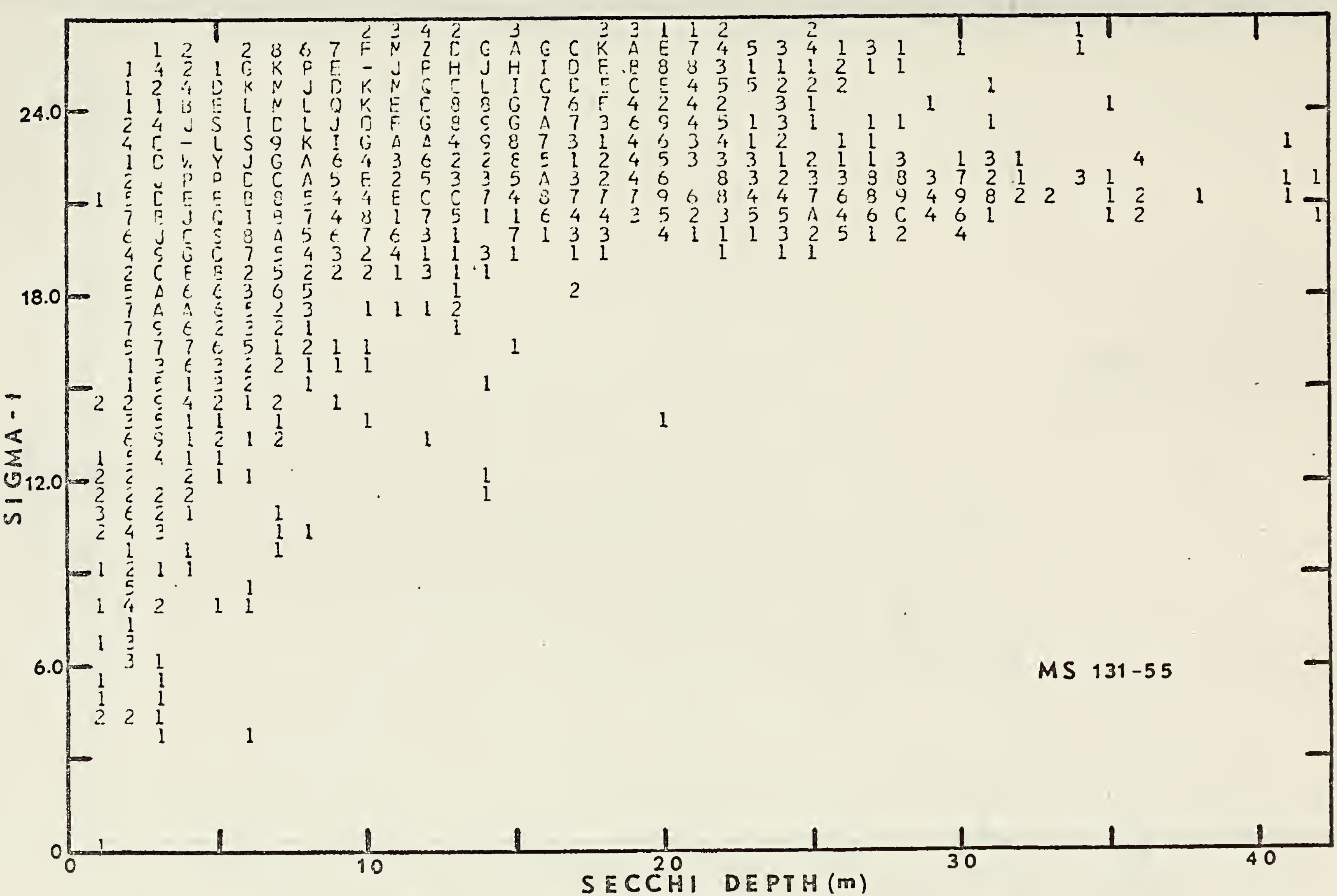

Figure 15. Surface sigma-t plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

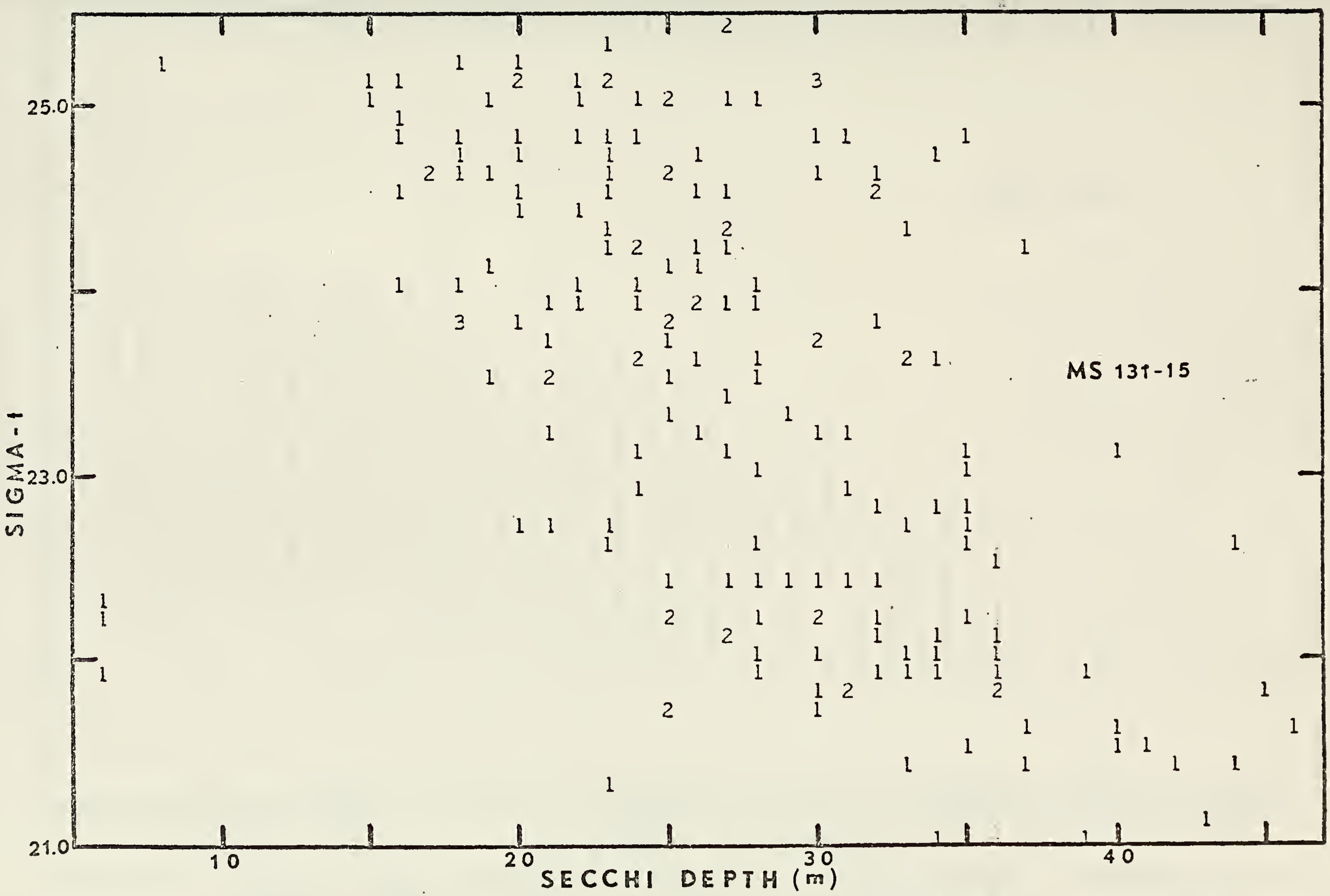

Figure 16. Surface sigma-t plotted as a function of Secchi depth. (Marsden square 131-15. Refer to Table IV for point density code.)

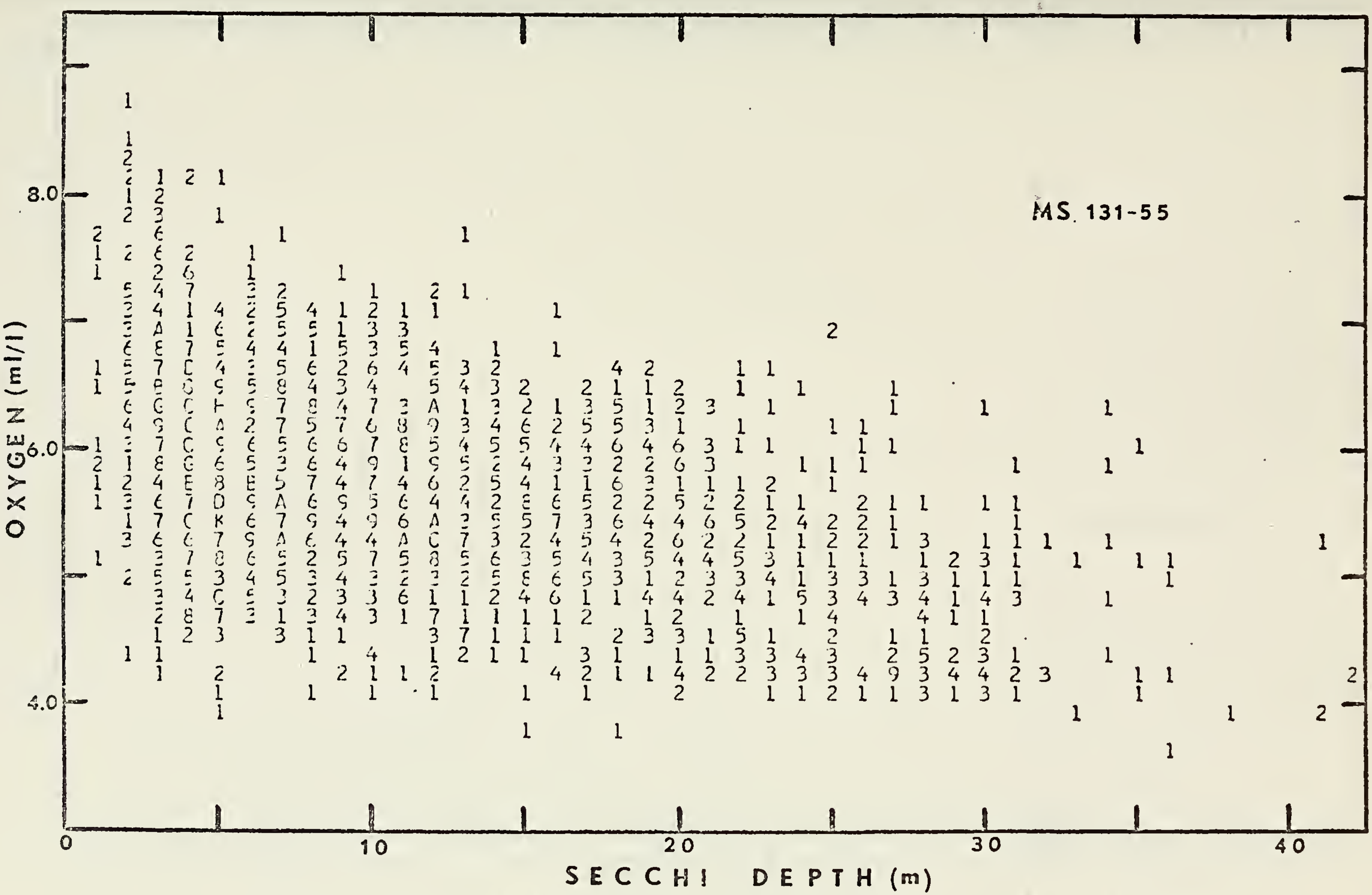

Figure 17. Surface oxygen plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

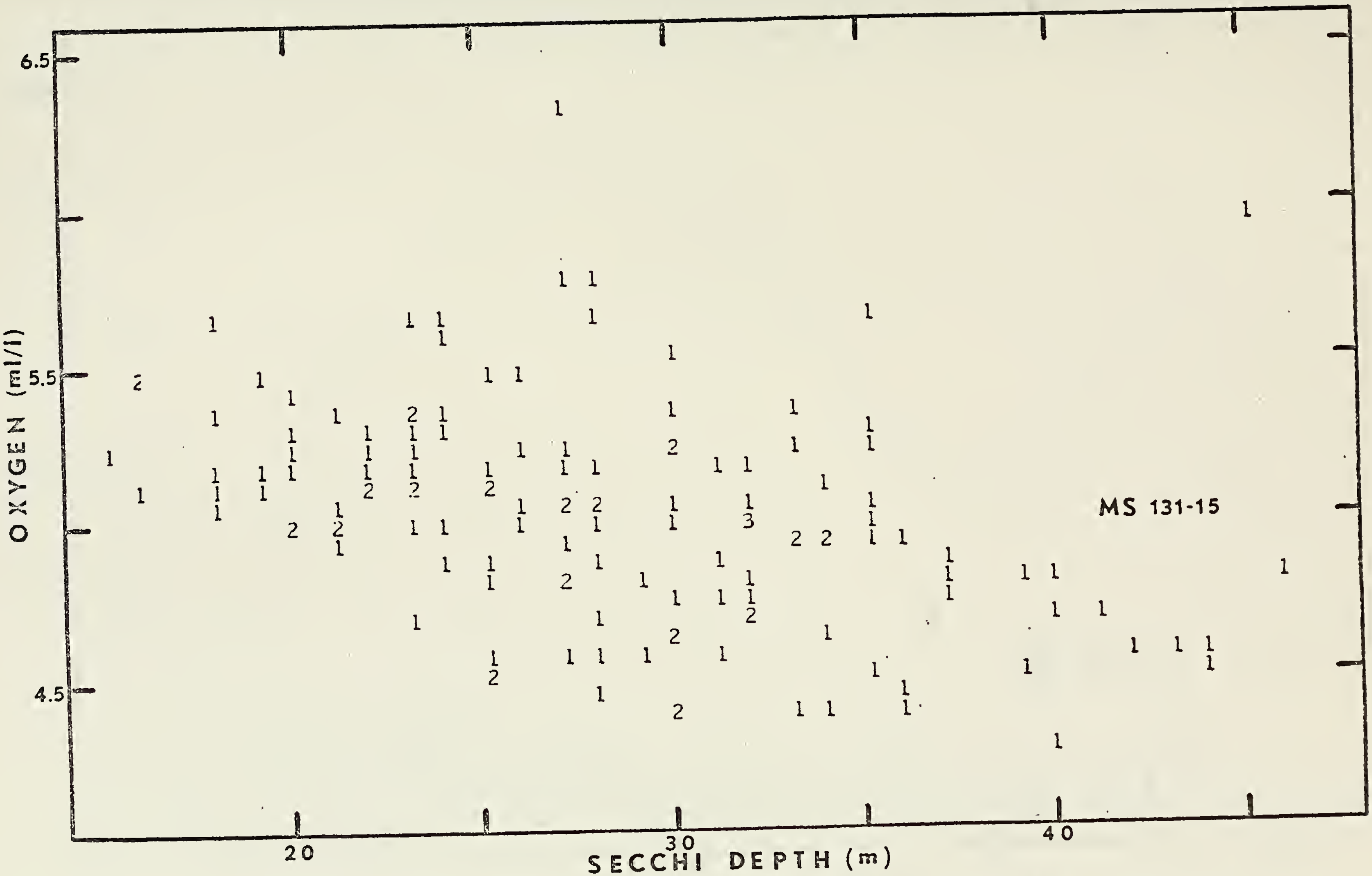

Figure 18. Surface oxygen plotted as a function of Secchi depth. (Marsden square 131-15. Refer to Table IV for point density code.)

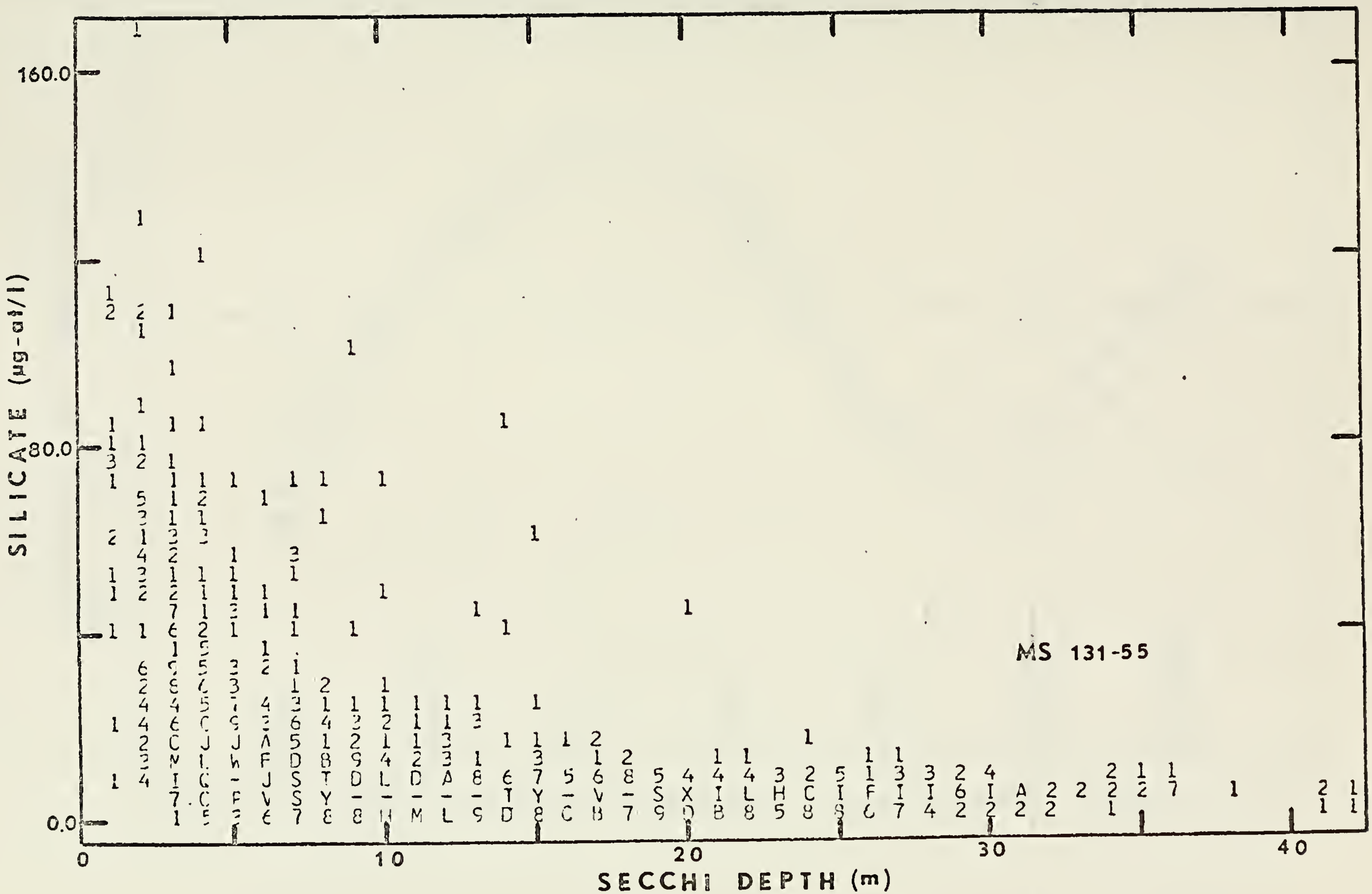

Figure 19. Surface silicate plotted as a function of Secchi depth. (Marsden square 131-55. Refer to Table IV for point density code.)

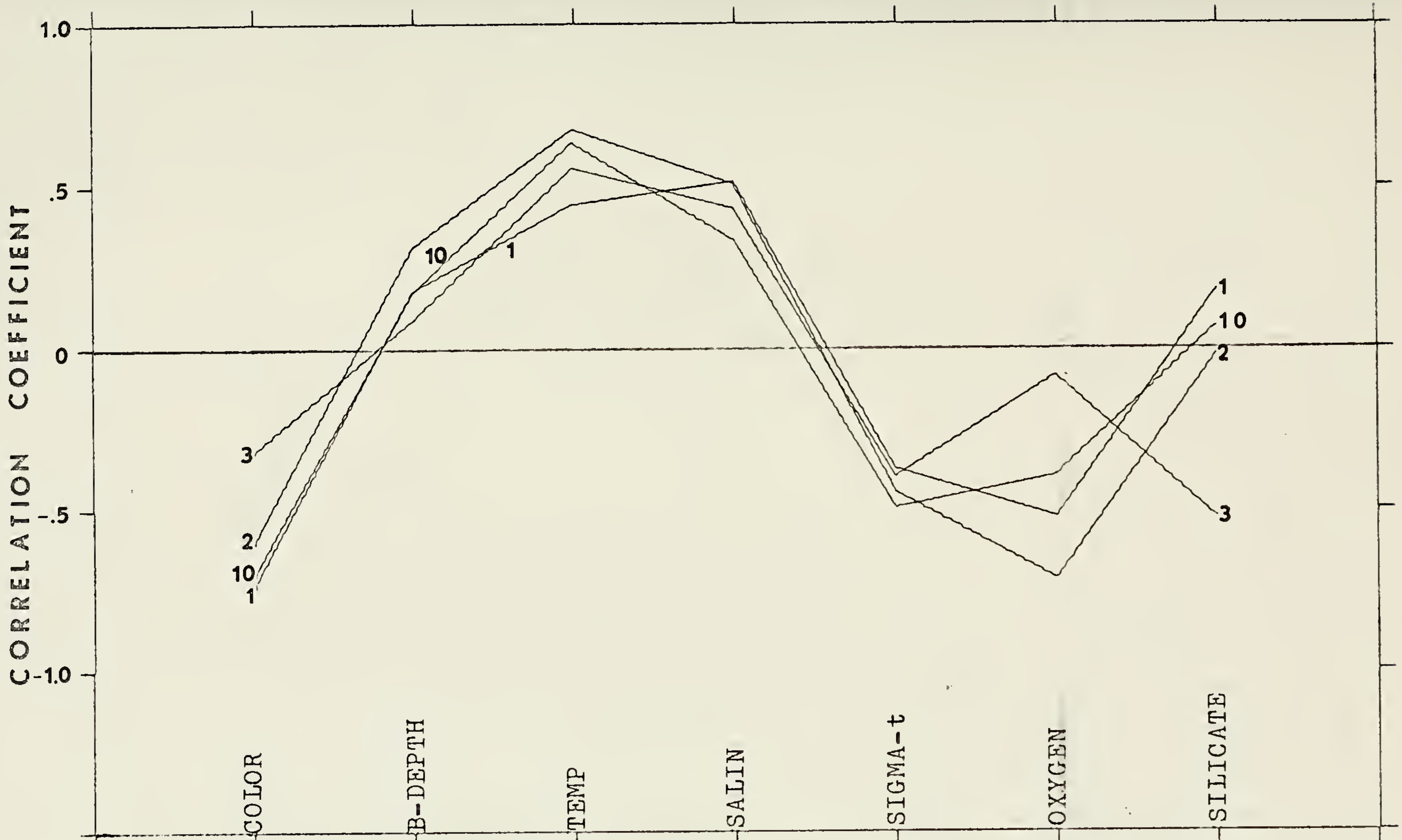

Figure 20A. Correlation coefficient graph - Atlantic Ocean. (Areas 1, 2, 3, 10.)

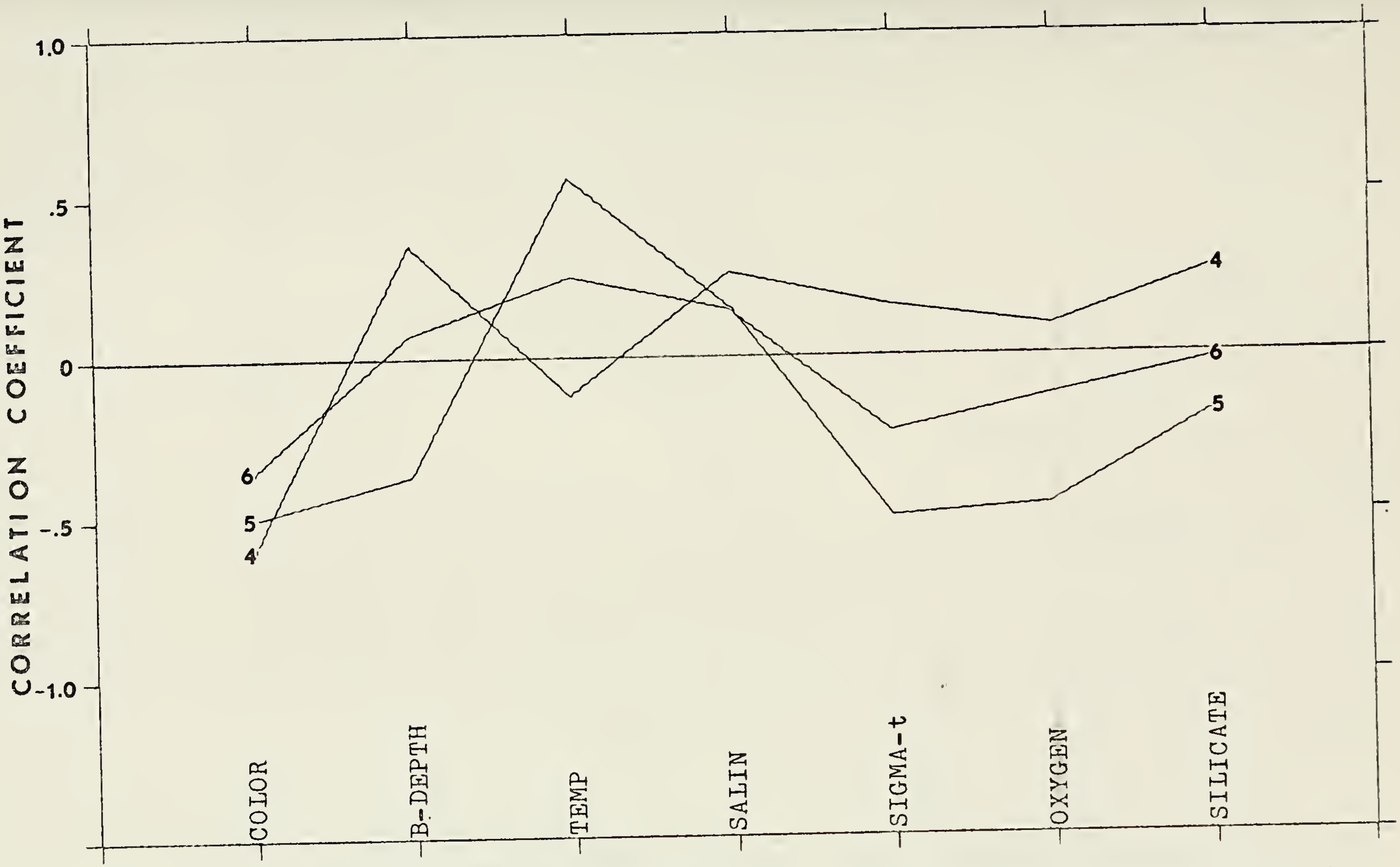

Figure 20B. Correlation coefficient graph - Pacific Ocean. (Areas 4, 5, 6)

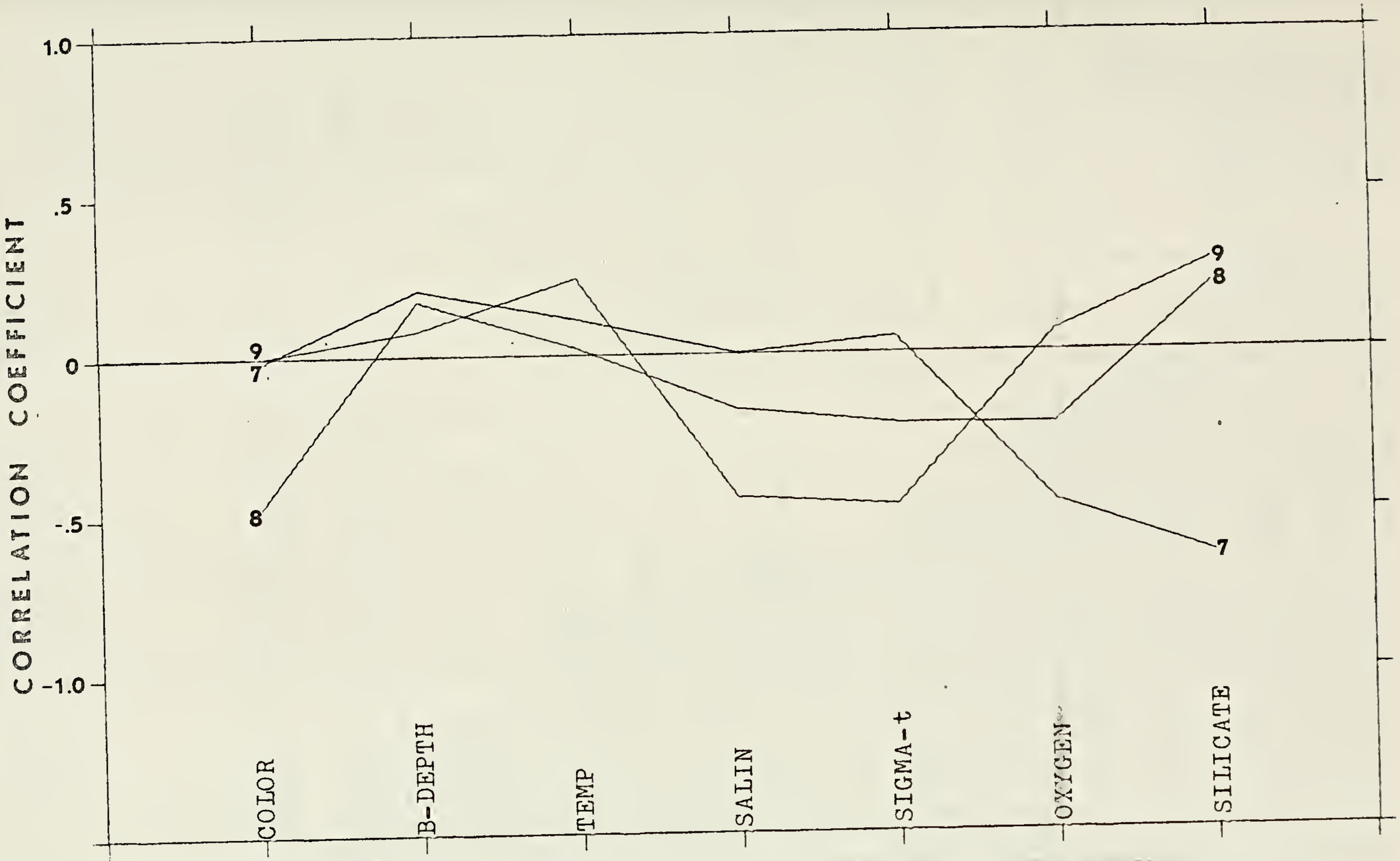

Figure 20C. Correlation coefficient graph - Pacific Ocean. (Areas 7, 8, 9.)

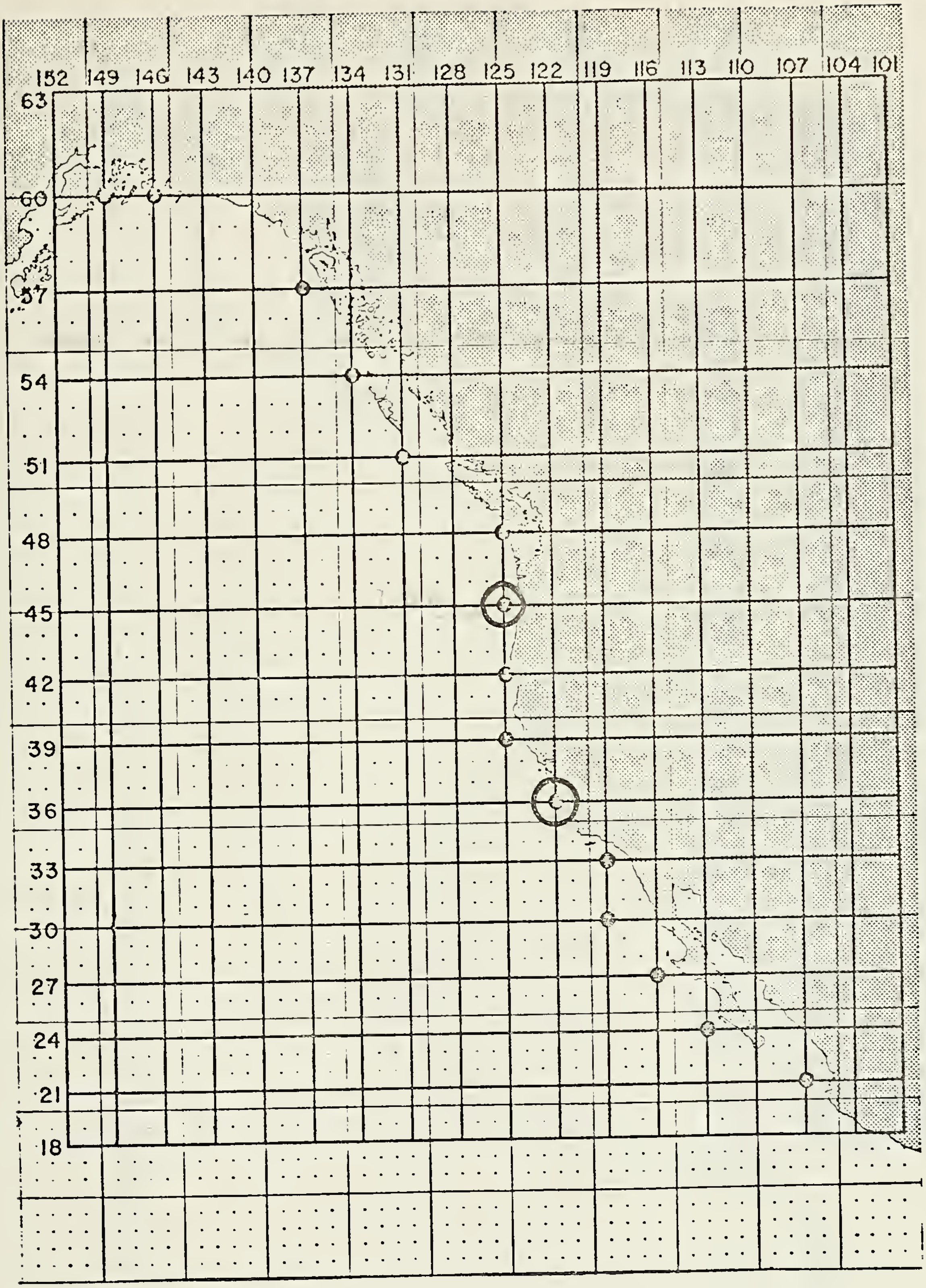

Figure 21. Points for which upwelling indices were computed by Bakun (1973). (Large circles indicate locations off Oregon and California for which comparisons were made with Secchi data.)

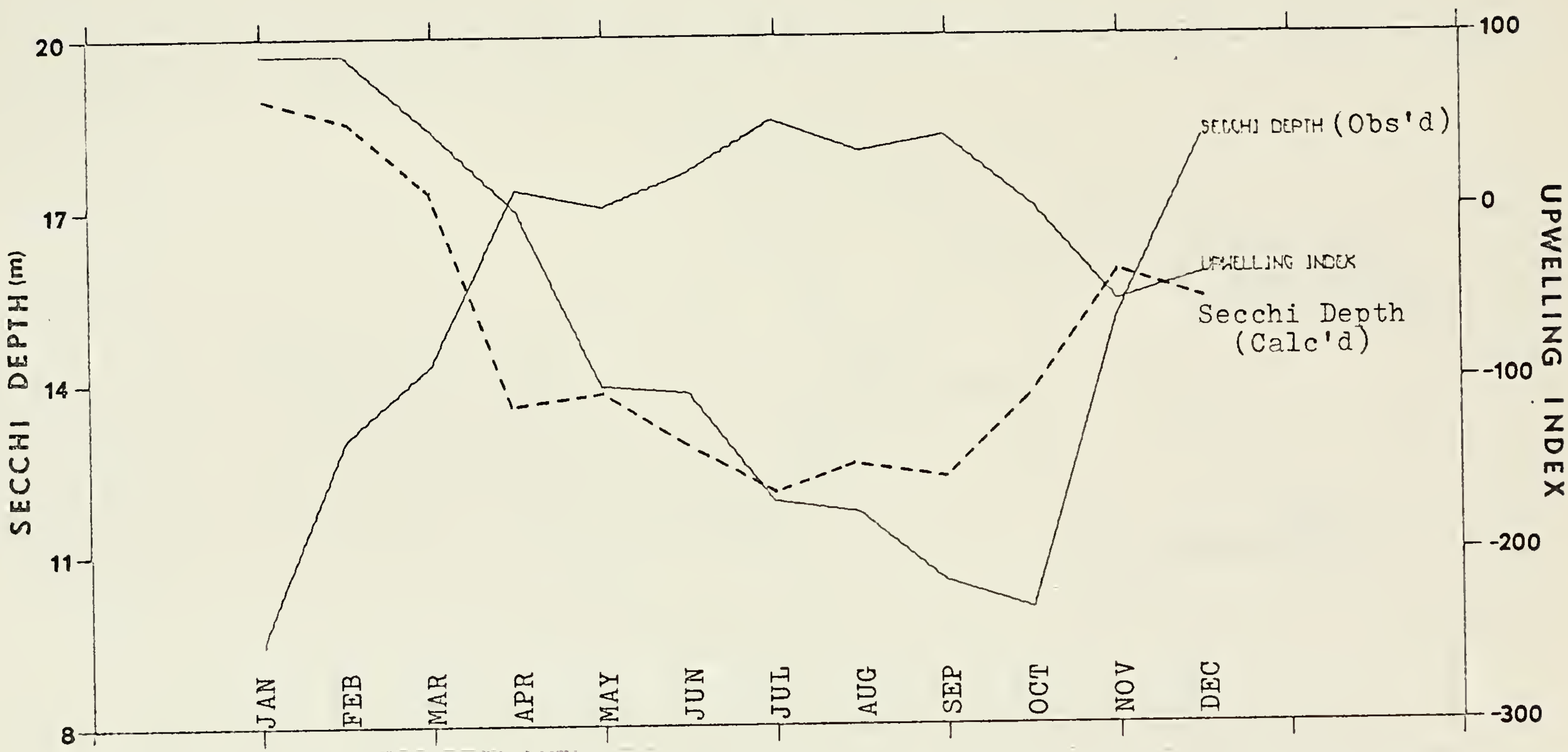

Figure 22. Secchi depth and upwelling index vs. month of year for the Oregon coast - 1961. [Observed Secchi depths are shown by a solid line. The dashed line corresponds to depths calculated according to the equation $Z_s = 13.83 - .04\, U + 3.13 \times 10^{-7}\, U^3$ (see Table XIII) which is based on the two years of Oregon data only.]

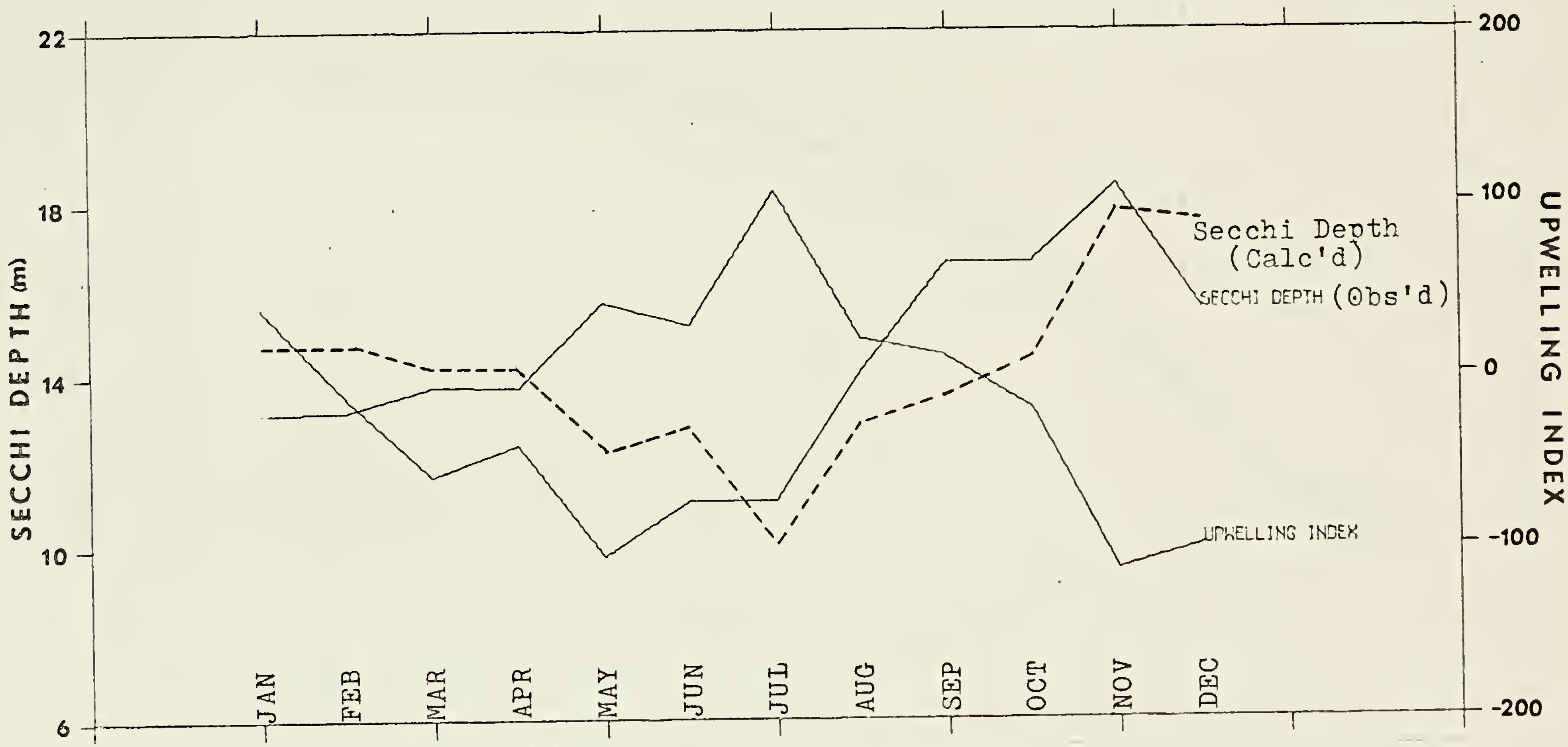

Figure 23. Secchi depth and upwelling index vs. month of year for the Oregon coast - 1962. [Observed Secchi depths are shown by a solid line. The dashed line corresponds to depths calculated according to the equation $Z_s = 13.83 - .04\,U + 3.13 \times 10^{-7}\,U^3$ (see Table XIII) which is based on the two years of Oregon data only.]

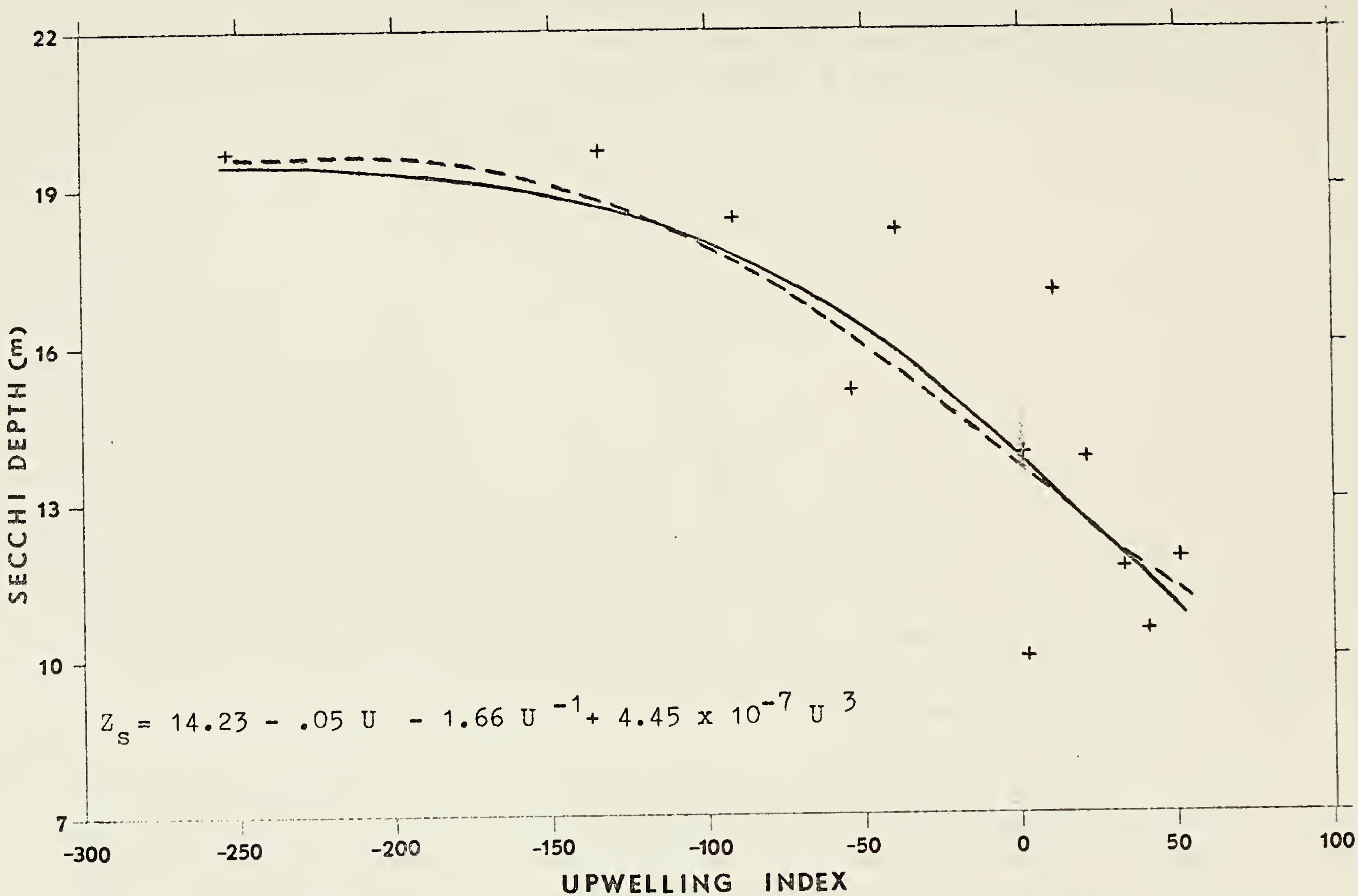

Figure 24. Secchi depth vs. upwelling index for the Oregon coast - 1961.

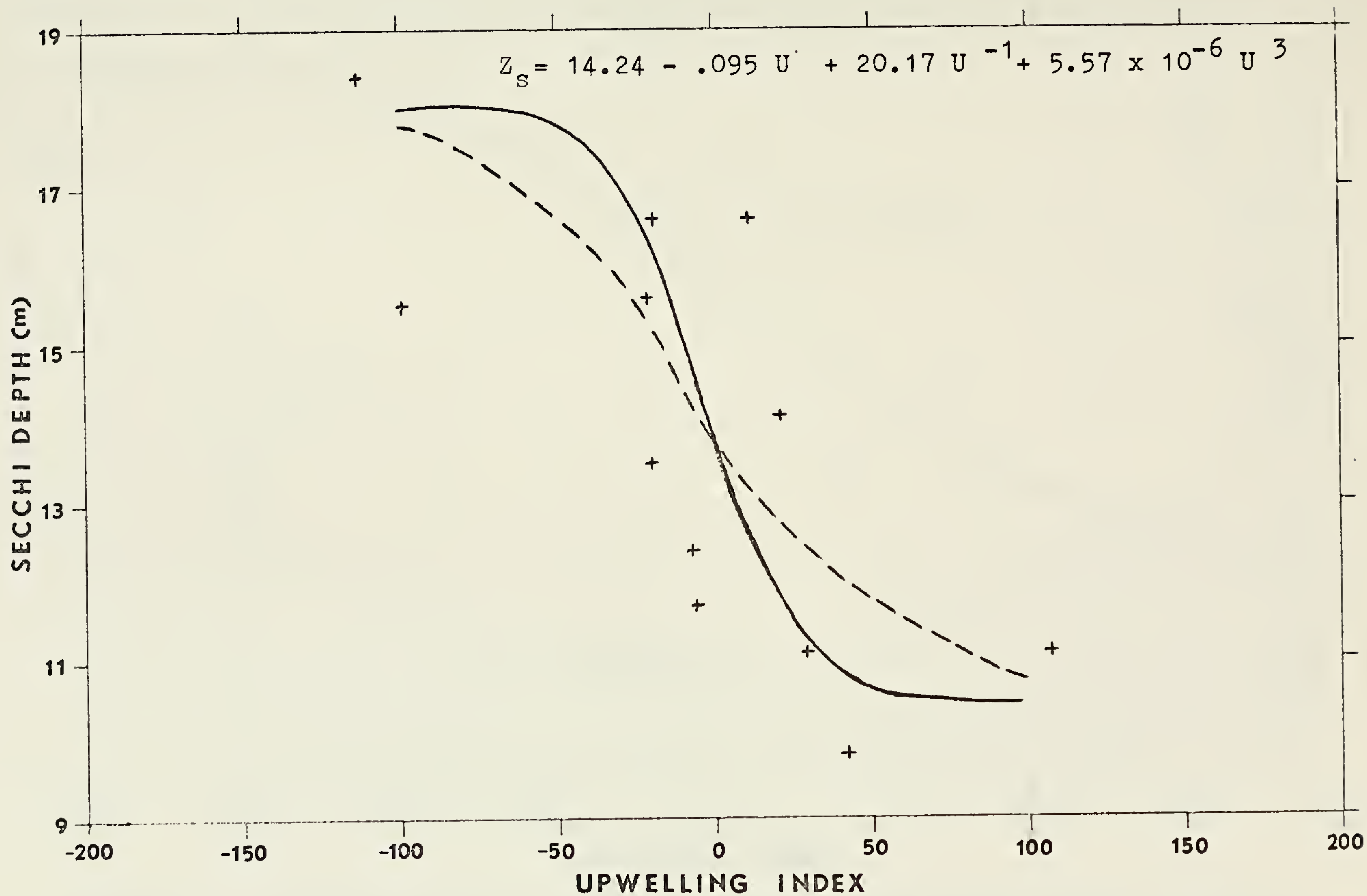

Figure 25. Secchi depth vs. upwelling index for the Oregon coast - 1962.

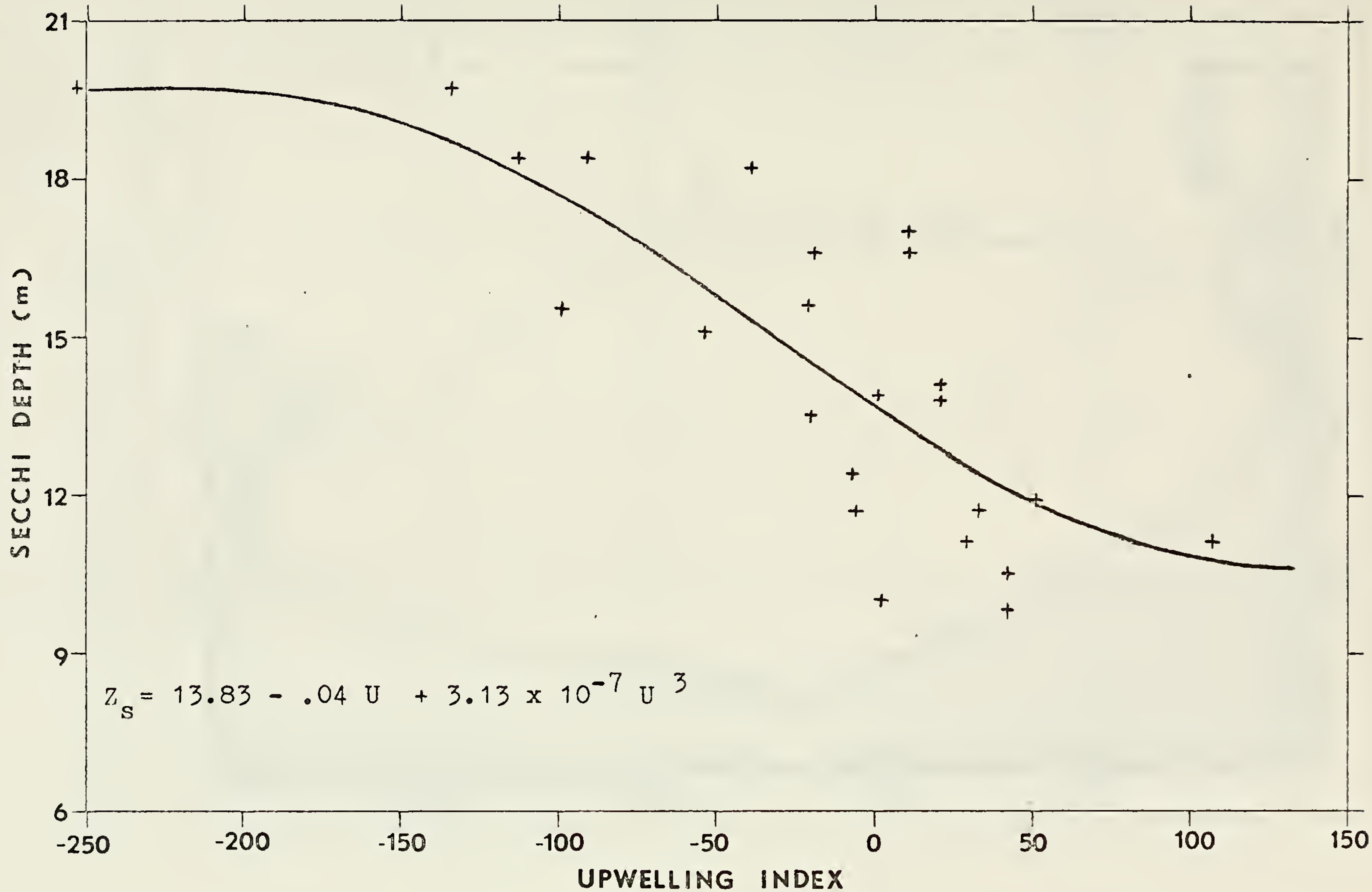

Figure 26. Secchi depth vs. upwelling index for the Oregon coast 1961-1962.

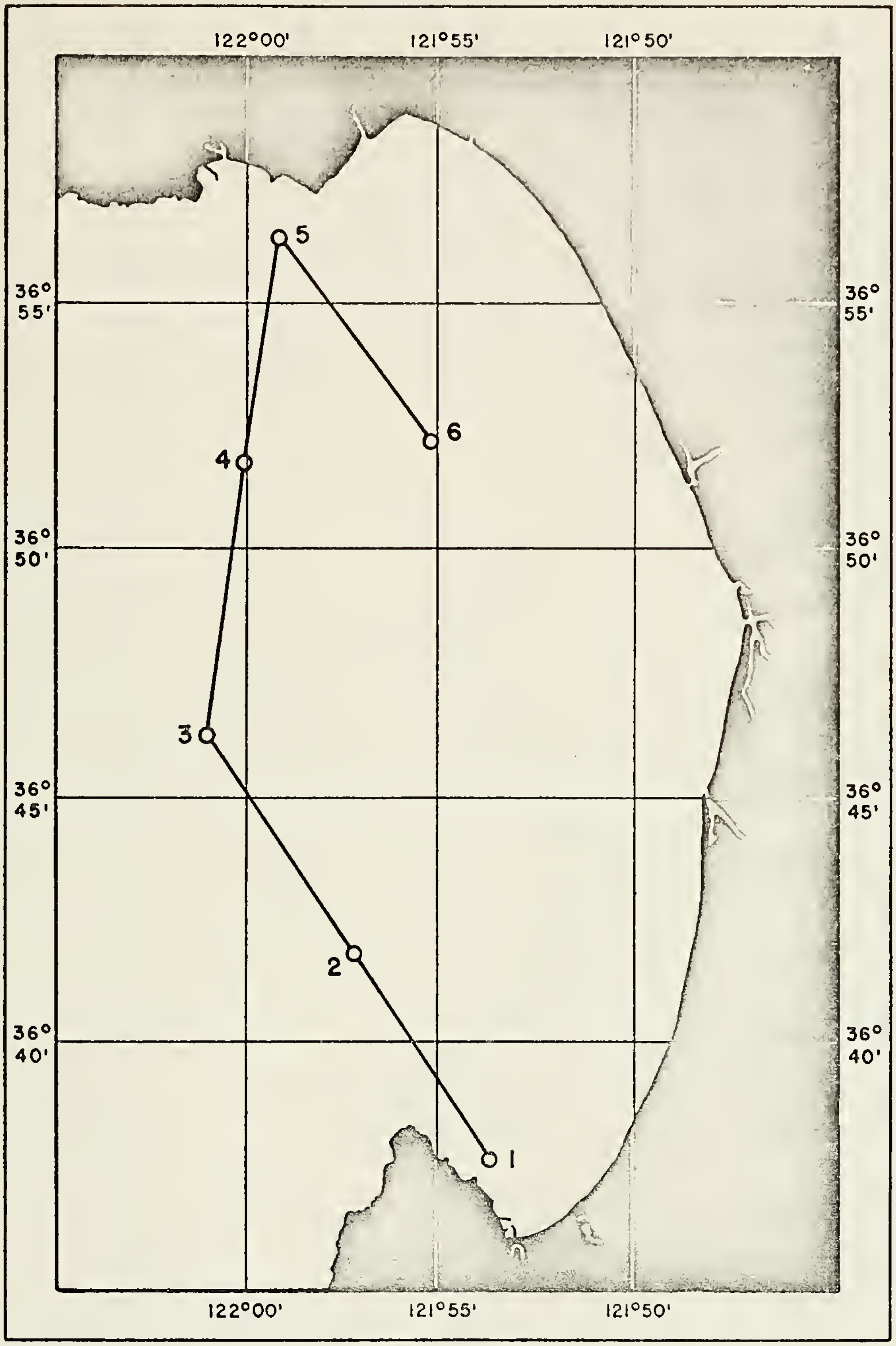

Figure 27. Monterey Bay, showing locations of CALCOFI stations occupied by Hopkins Marine Station of Stanford University.

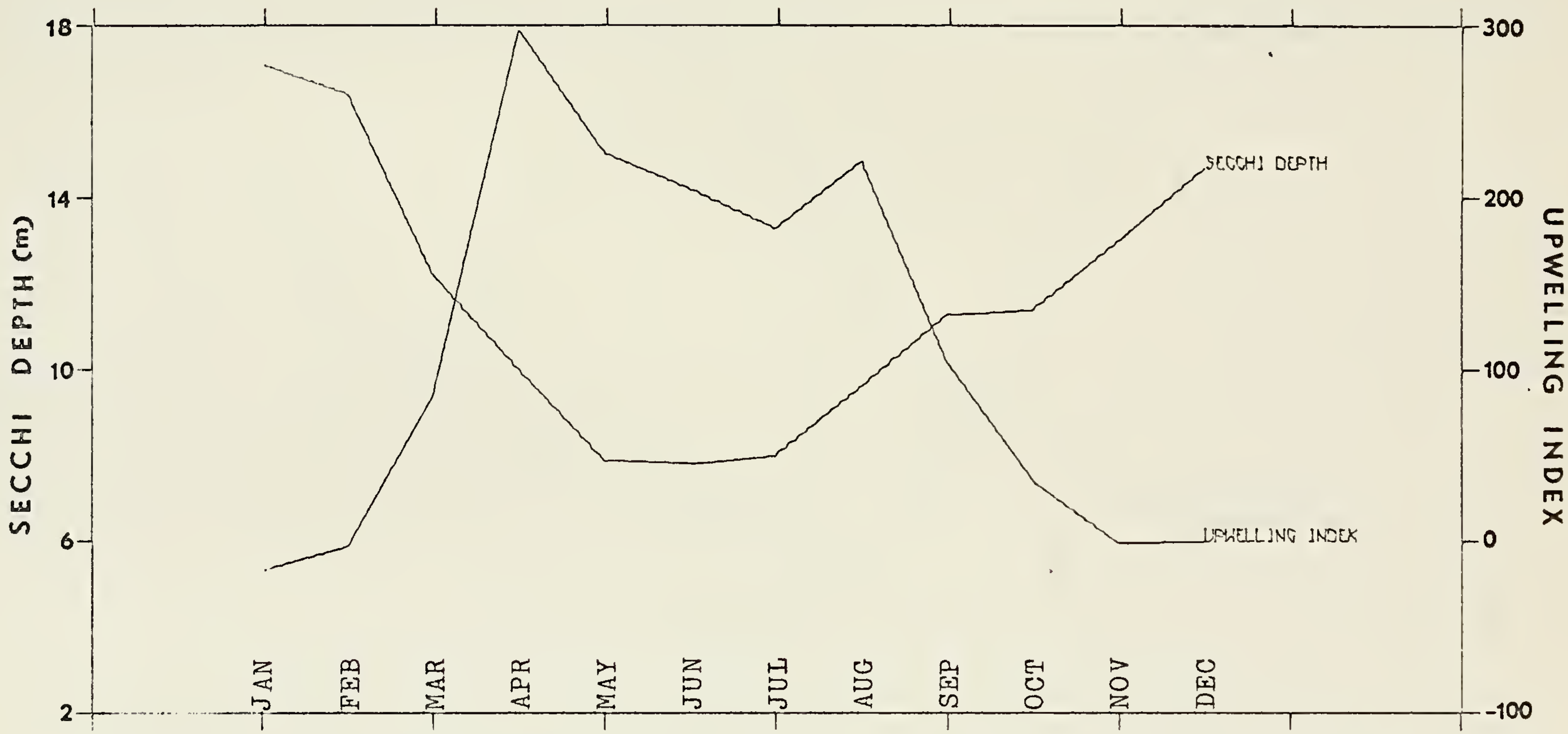

Figure 28. Secchi depth and upwelling index vs. month of year for Monterey Bay station 3 - 1970.

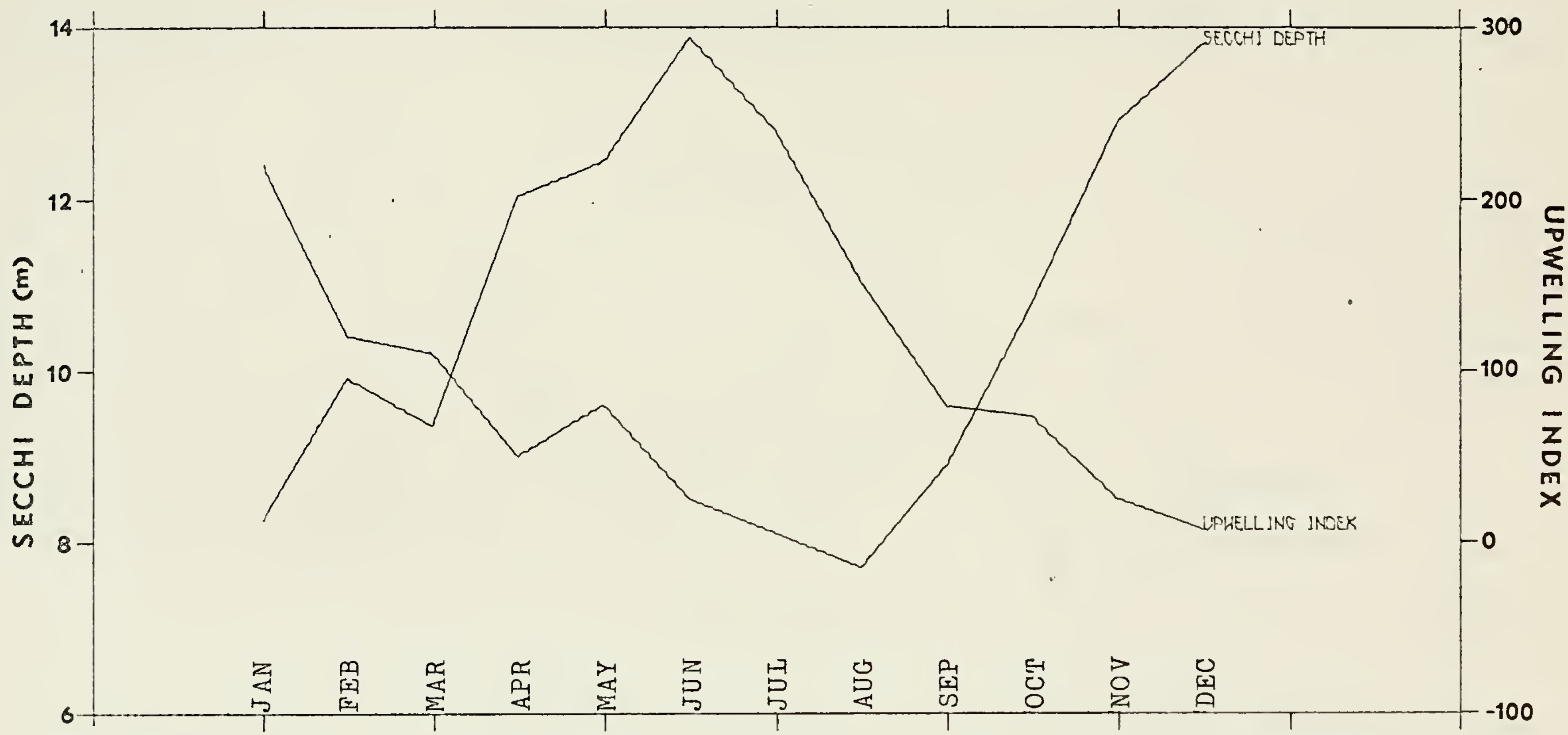

Figure 29. Secchi depth and upwelling index vs. month of year for Monterey Bay station 3 - 1971.

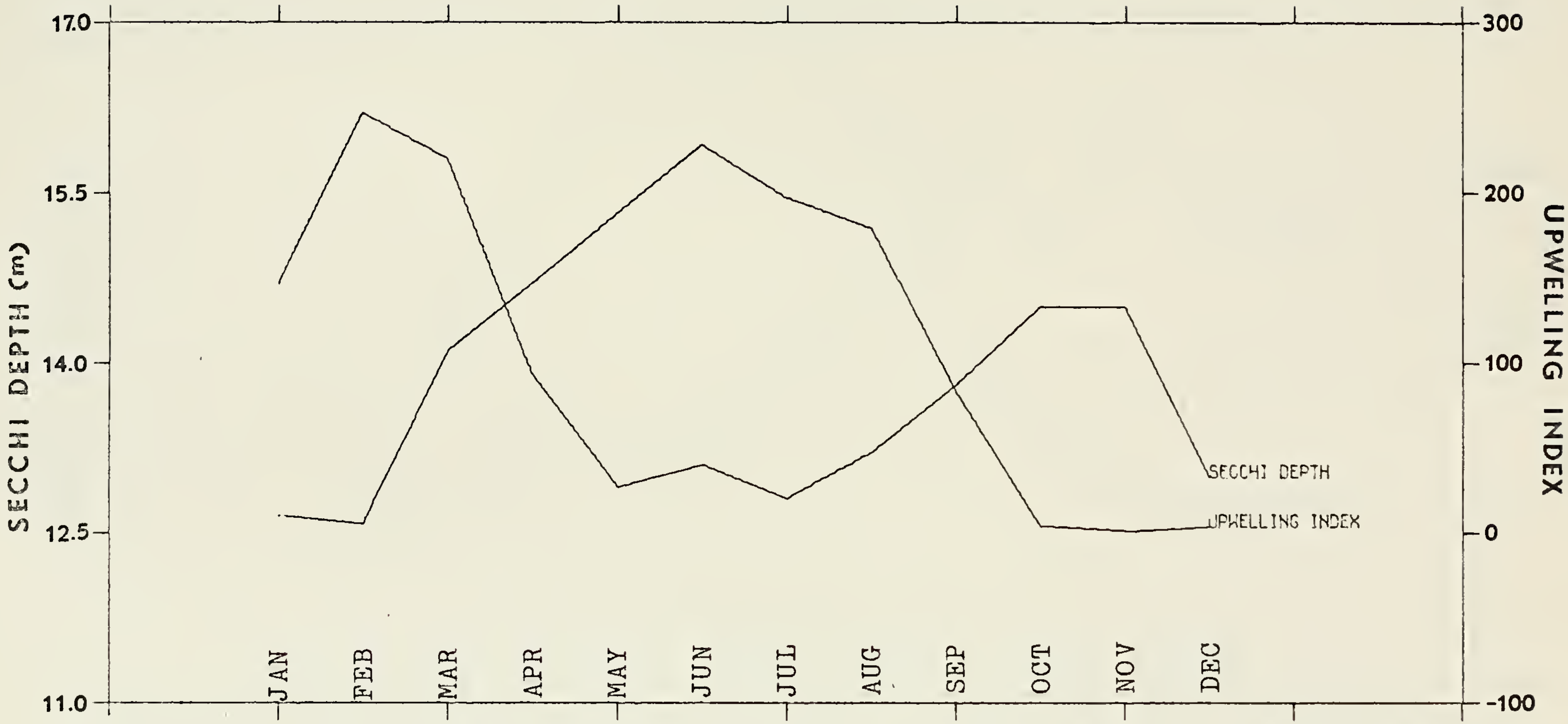

Figure 30. Secchi depth and upwelling index vs. month of year for Monterey Bay station 3 - 1972

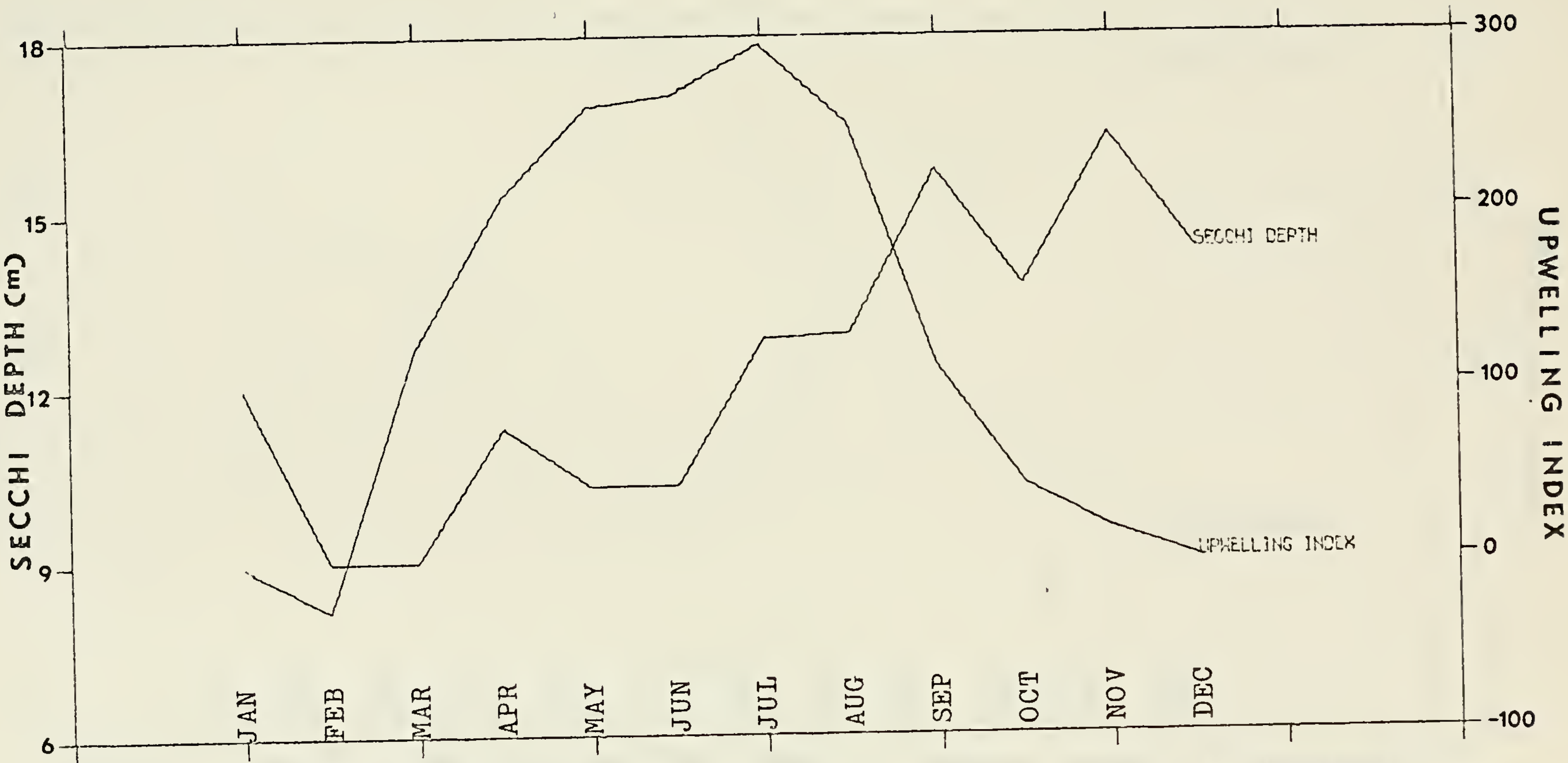

Figure 31. Secchi depth and upwelling index vs. month of year for Monterey Bay station 3 - 1973.

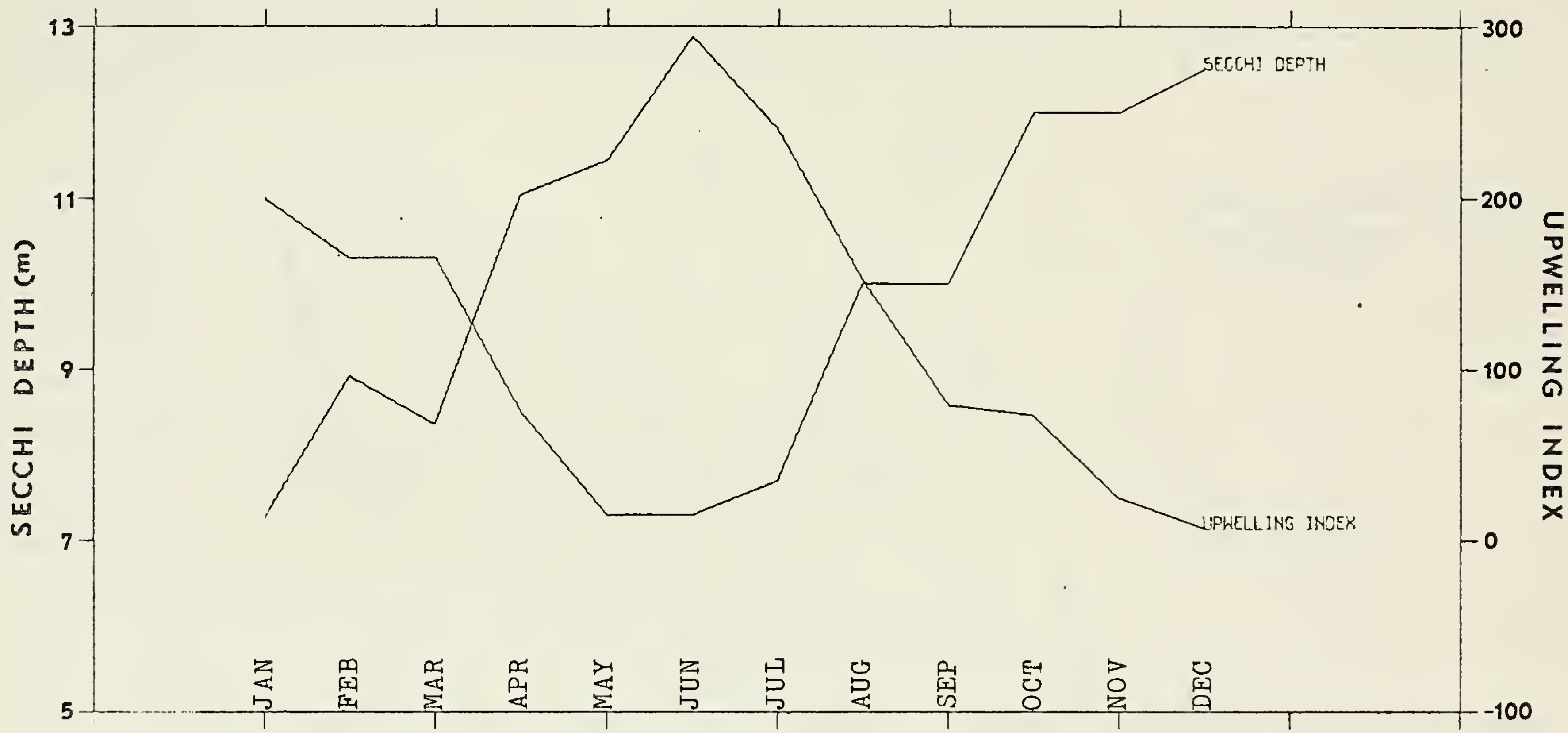

Figure 32. Secchi depth and upwelling index vs. month of year for Monterey Bay station 4 - 1971.

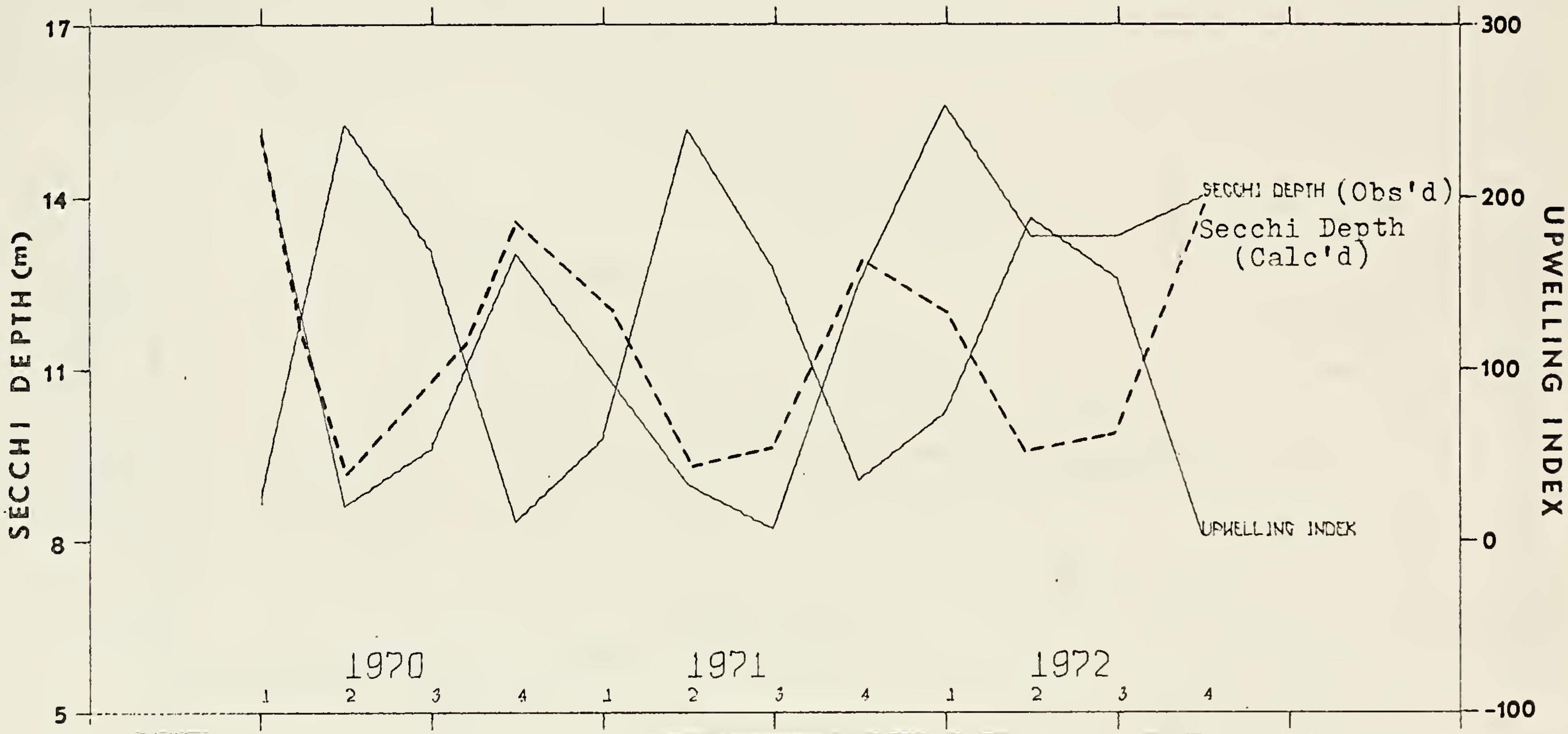

Figure 33. Secchi depth and upwelling index vs. quarter of year for Monterey Bay station 3 1970-1972. [Observed Secchi depths are shown by a solid line. The dashed line corresponds to depths calculated according to the equation $Z_s = 14.01 - .03\ U + 1.80 \times 10^{-7}\ U^3$ (see Table XIV) which is based on Oregon data for 1961-1962 and Monterey data for 1970-1973.]

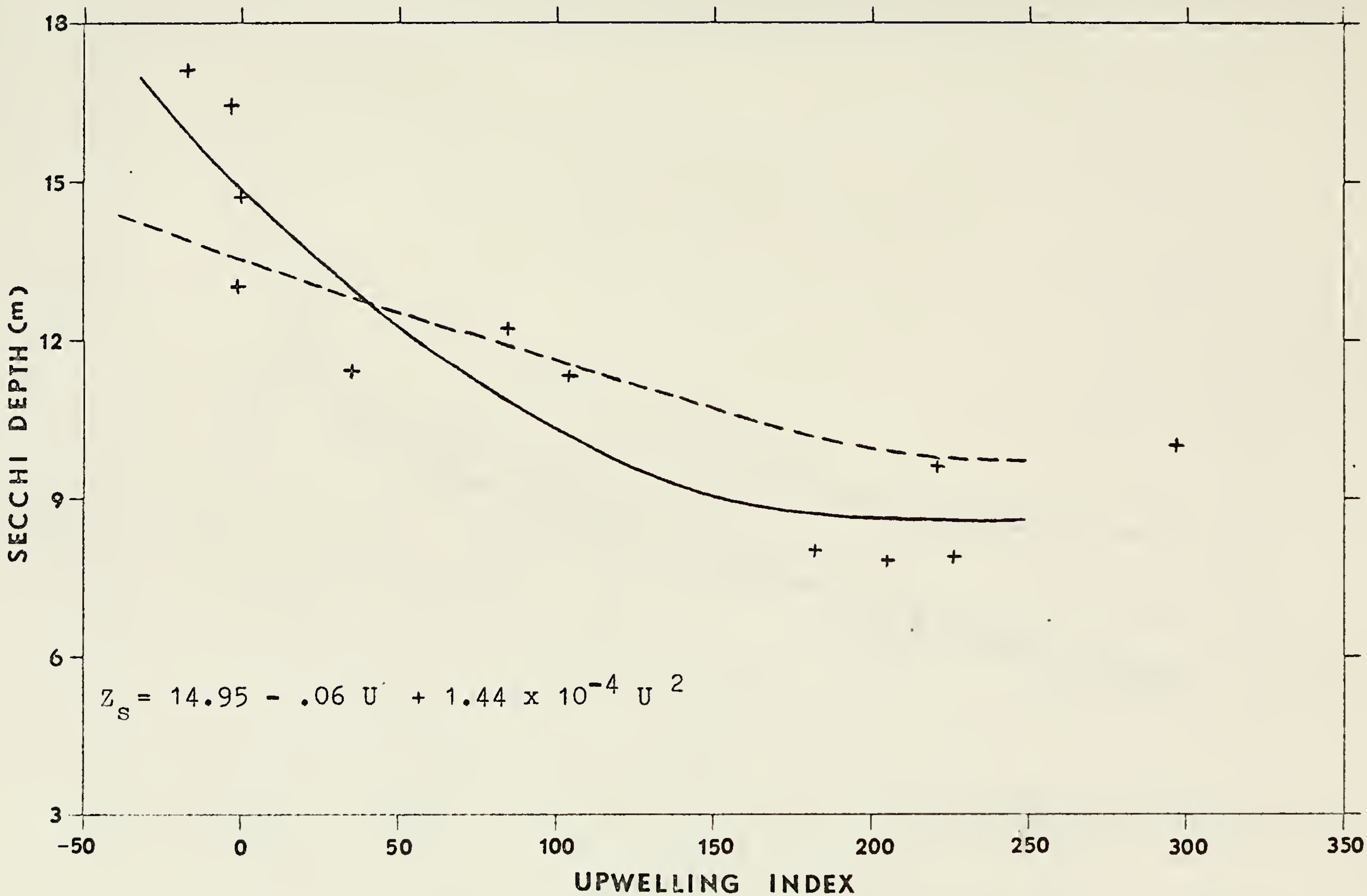

Figure 34. Secchi depth vs. upwelling index for Monterey Bay station 3 - 1970.

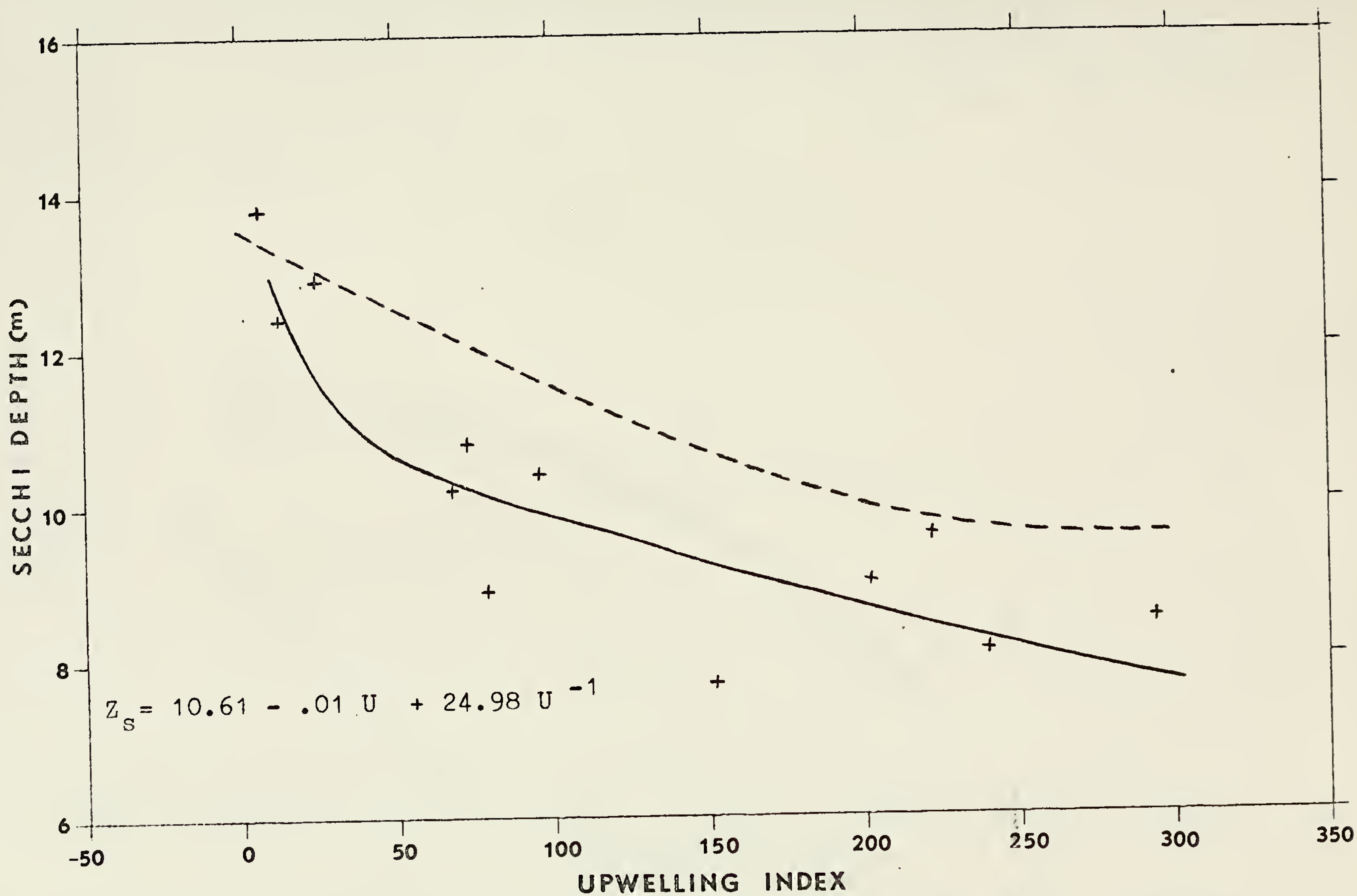

Figure 35. Secchi depth vs. upwelling index for Monterey Bay station 3 - 1971.

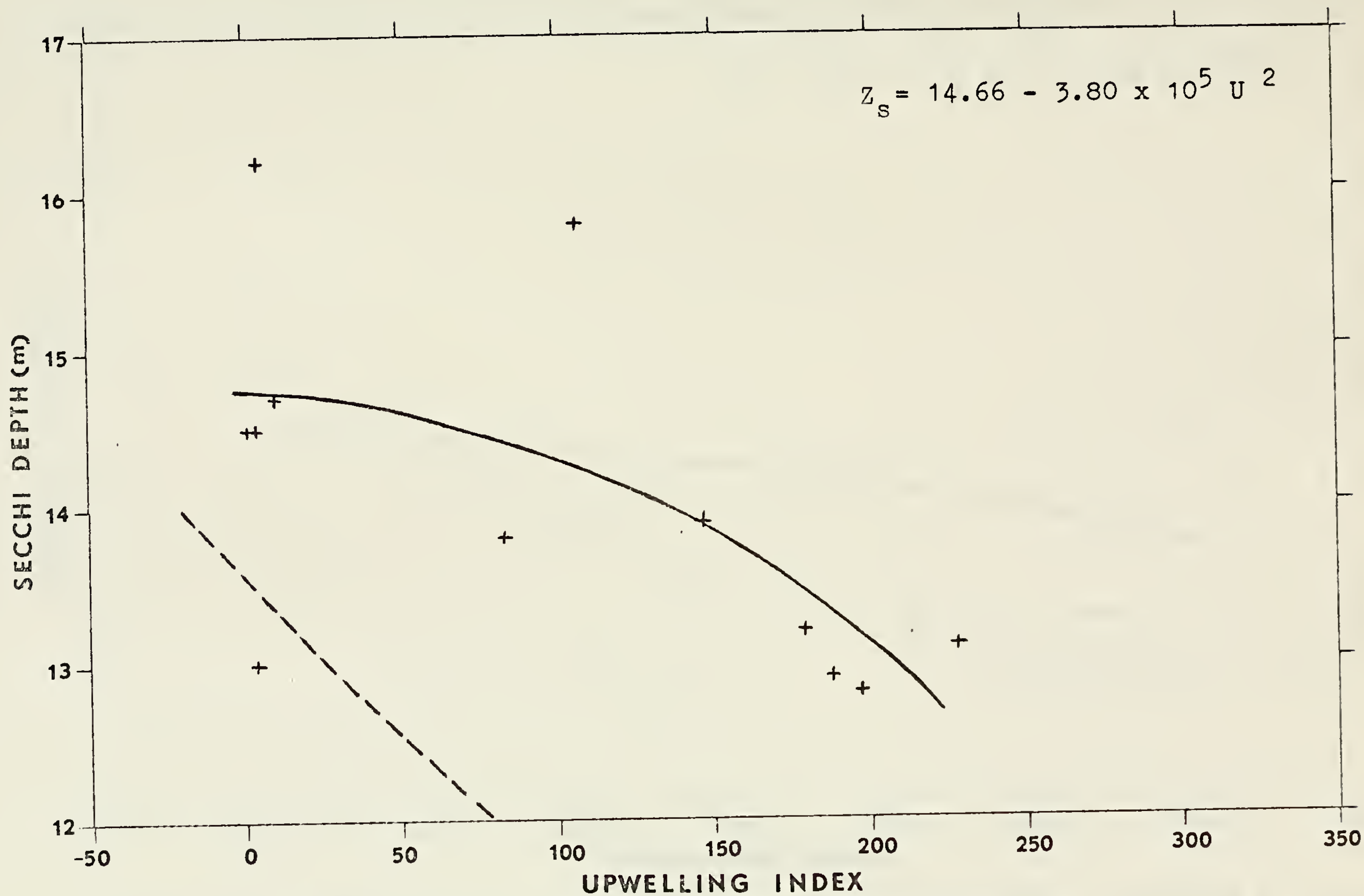

Figure 36. Secchi depth vs. upwelling index for Monterey Bay station 3 - 1972.

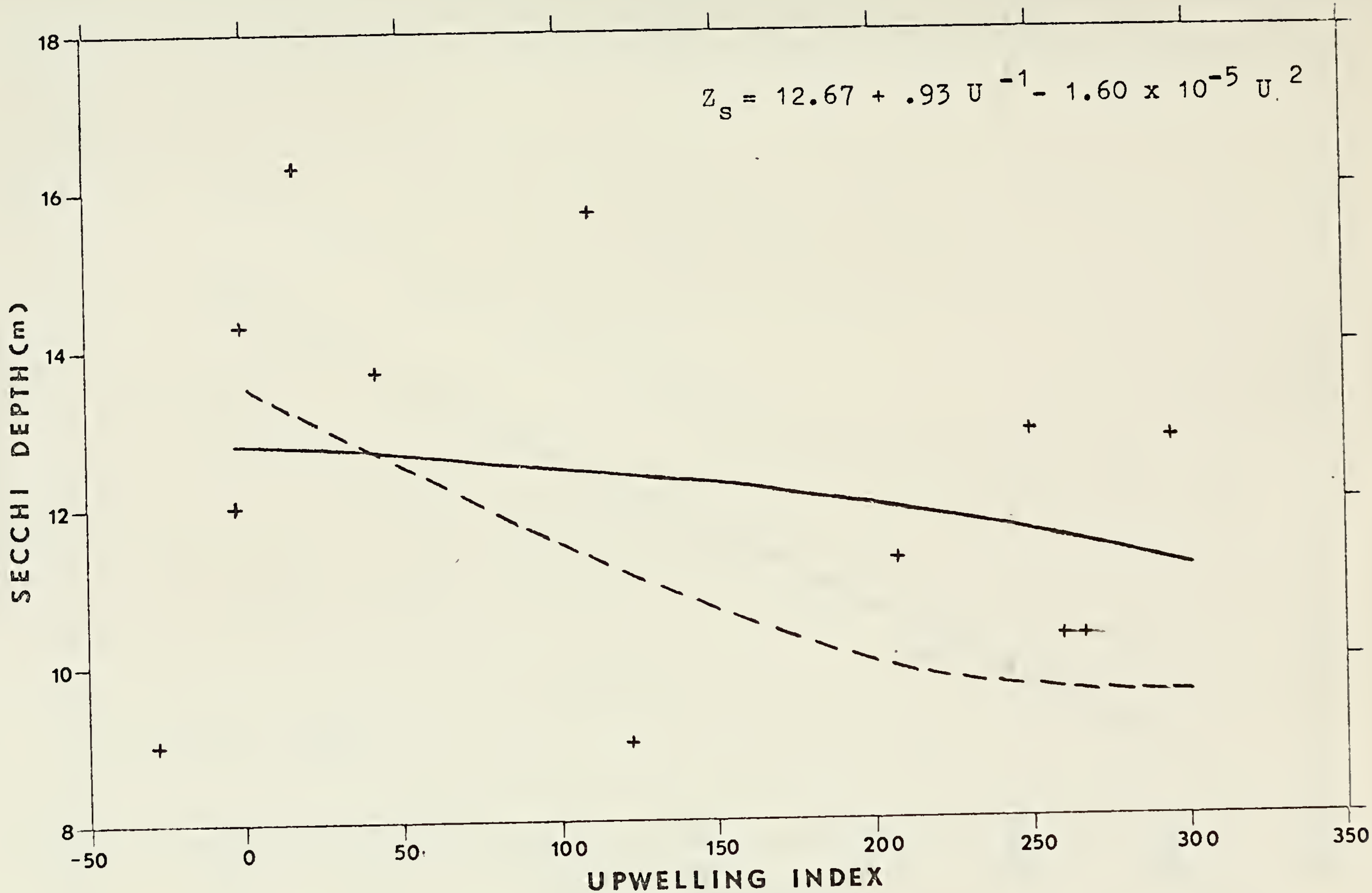

Figure 37. Secchi depth vs. upwelling index for Monterey Bay station 3 - 1973.

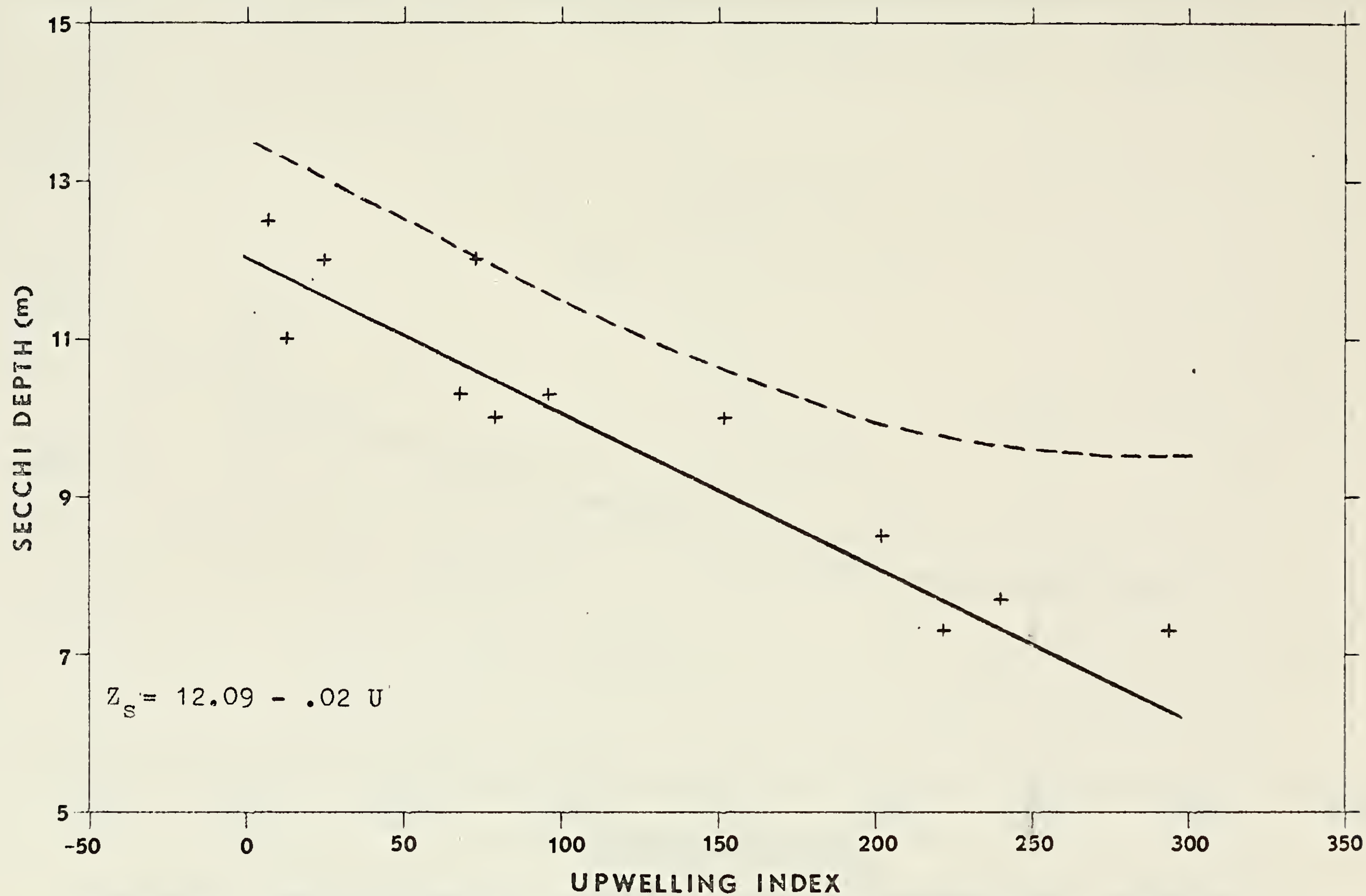

Figure 38. Secchi depth vs. upwelling index for Monterey Bay station 4 - 1971.

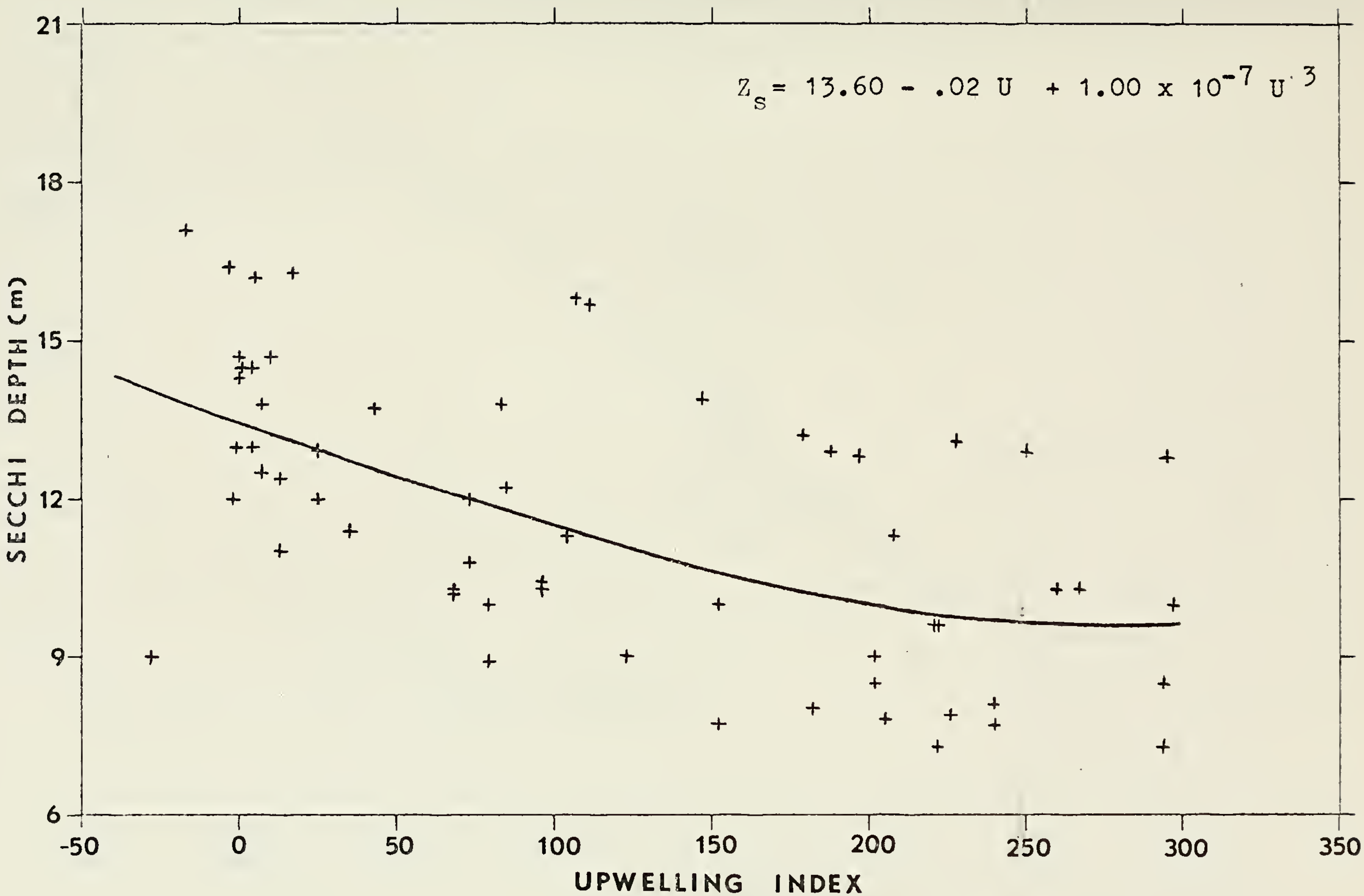

Figure 39. Secchi depth vs. upwelling index for Monterey Bay stations 3 and 4 1970-1973.

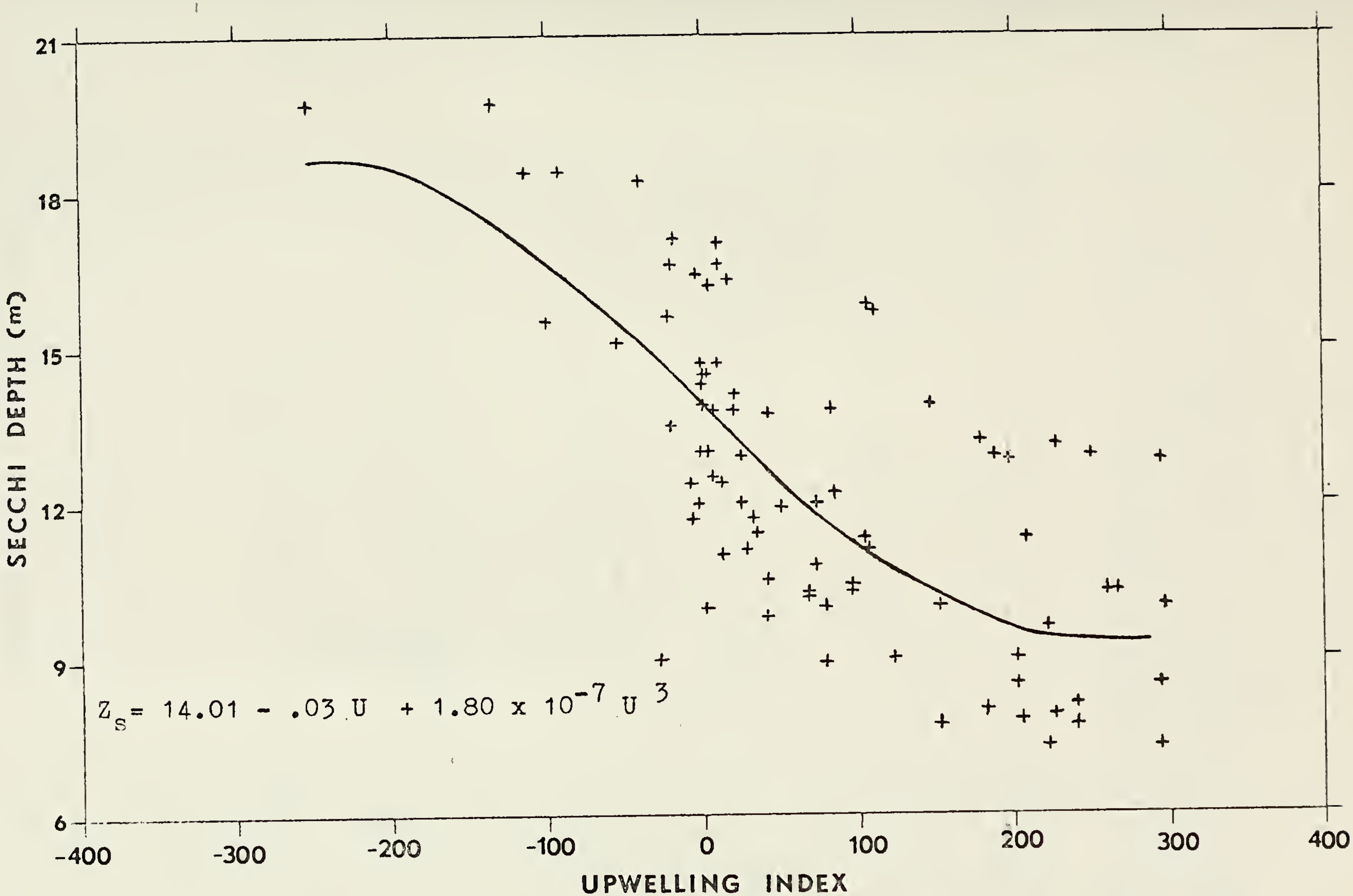

Figure 40. Secchi depth vs. upwelling index for the Oregon coast 1961-1962 and Monterey Bay stations 3 and 4 1970-1973.

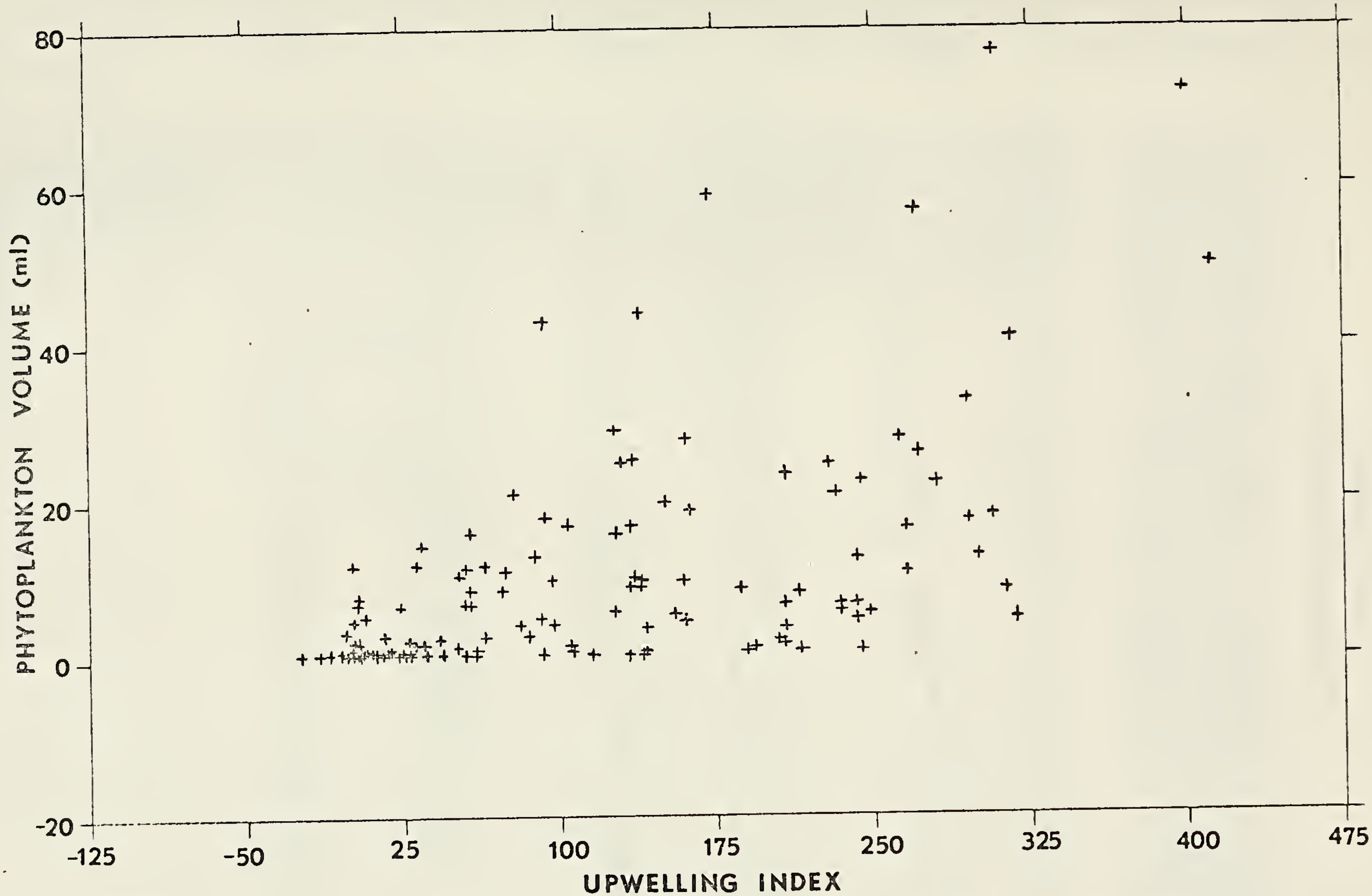

Figure 41. Phytoplankton wet volume vs. upwelling index for Monterey Bay 1956-1967.

APPENDIX A

AVERAGING PROGRAM

```
C
C       THIS PROGRAM READS SEQUENTIAL A-SHEET DATA, SCREENS
C       THE DATA AND THEN STORES THE SCREENED DATA IN PREPAR-
C       ATION FOR BIMED02D ANALYSIS.  EACH STATION LACKING A
C       SECCHI DEPTH MEASUREMENT IS OMITTED FROM ANALYSIS.
C       LATITUDE AND LONGITUDE CORRESPONDING TO EACH STATION
C       ARE SCREENED FOR THE AREA TO BE ANALIZED.  TEMPERA-
C       TURE, SALINITY, SIGMA-T, AND OXYGEN ARE THEN SCREENED
C       AND AVERAGED OVER THE SECCHI DEPTH.
C
C
        INTEGER*4 XD,XM,XTM,YD,YM,YTM
        DIMENSION TP(3500),TEMP(3500),SAL(3500),SIGMAT(3500),
       @OXY(3500)
        DATA TP/3500*0.0/,TEMP/3500*0.0/,SAL/3500*0.0/,SIGMAT
       @/3500*0.0/,OXY/3500*0.0/
        CALL REREAD
C
C       THIS SECTION OF THE PROGRAM SETS THE SUBSQUARE BOUN-
C       DARIES AND READS SEQUENTIAL DATA.
C
        N=1
        DSS=35.43
        DNN=36.0
        DEE=135.0
        DWW=136.0
      1 READ(5,10,END=80) XD,XM,XTM,YD,YM,YTM,DEPTH,ATEMP,
       @ASAL,ASIGMA,AOXY,KD
     10 FORMAT(1X,2I2,I1,1X,I3,I2,I1,5X,F4.0,F5.2,F4.2,F5.0,
       @5X,F4.0,24X,I1)
        IF(KD.GT.1) GO TO 1
     15 CONTINUE
C
C       THIS SECTION CONVERTS MINUTES AND SECONDS TO TENTHS OF
C       DEGREES.  LATITUDE AND LONGITUDE IS THEN CHECKED
C       AGAINST THE SUBSQUARE BOUNDARIES.
C
        A=0.0
        B=0.0
        C=0.0
        D=0.0
        IF((XM.EQ.0).AND.(XTM.EQ.0))   XTM=XTM+1
        IF((YM.EQ.0).AND.(YTM.EQ.0))   YTM=YTM+1
        ALAT=FLOAT(XD)+(FLOAT(XM)+(FLOAT(XTM)*.1))/60.0
        ALON=FLOAT(YD)+(FLOAT(YM)+(FLOAT(YTM)*.1))/60.0
        IF(ALAT.LT.DSS)   GO TO 1
        IF(ALON.LT.DEE)   GO TO 1
        IF(ALAT.GT.DNN)   GO TO 1
        IF(ALON.GT.DWW)   GO TO 1
C
C       THIS SECTION SCREENS THE DATA, AVERAGES THE DATA OVER
C       THE SECCHI DEPTH, AND THEN PLACES THE DATA IN STORAGE
C       FOR BIMED02D ANALYSIS.
C
        BTEMP=0.0
        DTEMP=0.0
        ITEMP=0
        ETEMP=0.0
        FTEMP=0.0
        GTEMP=0.0
        BSAL=0.0
        ISAL=0
        DSAL=0.0
        SECCHI=0.0
        IF((ATEMP.EQ.0.0).AND.(ASAL.EQ.0.0)) GO TO 1
        IF(ATEMP.EQ.0.0) GO TO 20
        BTEMP=ATEMP*100.0
        DTEMP=ATEMP*10.0
```

```
      ITEMP=DTEMP
      ITEMP=ITEMP*10
      ETEMP=FLOAT(ITEMP)
      FTEMP=BTEMP-ETEMP
      GTEMP=FTEMP*10.0
      GO TO 25
   20 GTEMP=0.0
   25 IF(ASAL.EQ.0.0) GO TO 30
      BSAL=ASAL/10.0
      ISAL=BSAL
      DSAL=FLOAT(ISAL)
      GO TO 35
   30 DSAL=0.0
   35 SECCHI=GTEMP+DSAL
      IF(SECCHI.LE.0.1) GO TO 1
      CTEMP=0.0
      CSAL=0.0
      CSIGMA=0.0
      COXY=0.0
   40 READ(5,10,END=80) XD,XM,XTM,YD,YM,YTM,DEPTH,ATEMP,
     @ASAL,ASIGMA,AOXY,KD
      IF(KD.EQ.1) GO TO 65
      IF(ATEMP.EQ.0.0) GO TO 45
      A=A+1.0
      CTEMP=CTEMP+ATEMP
   45 IF(ASAL.EQ.0.0) GO TO 50
      B=B+1.0
      CSAL=CSAL+ASAL
   50 IF(ASIGMA.EQ.0.0) GO TO 55
      C=C+1.0
      CSIGMA=CSIGMA+ASIGMA
   55 IF(AOXY.EQ.0.0) GO TO 60
      D=D+1.0
      COXY=COXY+AOXY
   60 CONTINUE
      GO TO 40
   65 CONTINUE
      TP(N)=SECCHI
      IF(TP(N).LE.0.1) GO TO 70
      IF(TP(N).GE.99.0) GO TO 70
      IF(A.EQ.0.0) TEMP(N)=0.0
      IF(A.GT.0.0) TEMP(N)=CTEMP/A
      IF(B.EQ.0.0) SAL(N)=0.0
      IF(B.GT.0.0) SAL(N)=CSAL/B
      IF(C.EQ.0.0) SIGMAT(N)=0.0
      IF(C.GT.0.0) SIGMAT(N)=CSIGMA/C
      IF(D.EQ.0.0) OXY(N)=0.0
      IF(D.GT.0.0) OXY(N)=COXY/D
      GO TO 75
   70 CONTINUE
      TP(N)=0.0
      GO TO 15
   75 CONTINUE
      N=N+1
      GO TO 15
   80 CONTINUE
      L=N-1
      NUM=L
      WRITE(8,90)(TP(N),TEMP(N),SAL(N),SIGMAT(N),
     @OXY(N),N=1,L)
   90 FORMAT(F8.0,F6.2,F5.2,F6.0,F5.0)
      WRITE(6,100) NUM
  100 FORMAT('0','TOTAL COUNT THIS SUBSQUARE:',I7)
      STOP
      END
```

APPENDIX B

SAMPLE BIMED02D OUTPUT

```
BMD02D CORRELATION WITH TRANSGENERATION
REVISED JANUARY 29, 1970
HEALTH SCIENCES COMPUTING FACILITY,UCLA

PROBLEM CODE    TEMP
NUMBER OF VARIABLES    2
NUMBER OF CASES   3399



CASE SELECTION CARDS


A CASE IS ACCEPTED IF
(VAR(   2) NE 0.0000) **
VARIABLE FORMAT CARD (S)
(F8.0,F6.2)


REMAINING SAMPLE SIZE= 3399

SUMS


    36683.0000     61336.2617

MEANS


       10.7923        18.0454

CROSS PRODUCT DEVIATIONS

         COL.              COL.
           1                 2
  1178283.2500      41609.7930
  2141609.7930     105265.5625

STANDARD DEVIATIONS


         7.2434          5.5658

VARIANCE-COVARIANCE MATRIX



         COL.              COL.
           1                 2
  1      52.4671          12.2454
  2      12.2454          30.9787

CORRELATION MATRIX



         COL.              COL.
           1                 2
  1      1.0000           0.3037
  2      0.3037           1.0000
```

APPENDIX C

TIME SERIES ANALYSIS

```
C
C     THIS PROGRAM READS SEQUENTIAL A-SHEET DATA AND SORTS
C     SECCHI DEPTH OBSERVATIONS ACCORDING TO YEAR AND MONTH
C     OF OBSERVATION.  SECCHI DEPTH MEASUREMENTS ARE THEN
C     AVERAGED FOR EACH MONTH IN THE AREA OF ANALYSIS.
C
      INTEGER*4  XD,XM,YD,YM
      DIMENSION  TOTSEC(72,12),DIVIDE(72,12),AVSEC(72,12)
      DATA  NLAT/43/,NLONG/124/,NLA/46/,NLO/128/,N/0/,N1/0/,
     @MYEAR/0/
      CALL REREAD
      DO 2 I=1,72
      DO 1 J=1,72
      TOTSEC(I,J)=0.0
      DIVIDE(I,J)=0.0
      AVSEC(I,J)=0.0
    1 CONTINUE
    2 CONTINUE
C
C     THIS SECTION READS IN SEQUENTIAL STATIONS AND CHECKS
C     LATITUDE AND LONGITUDE TO INSURE THEY ARE WITHIN THE
C     AREA OF ANALYSIS.  STATIONS ARE THEN SCREENED FOR
C     ERRONEOUS MONTHS AND YEARS AND CHECKED FOR ZERO SECCHI
C     DEPTHS.  SECCHI DEPTHS ARE THEN AVERAGED FOR EACH
C     MONTH.
C
    5 READ(5,10,END=15) XD,XM,YD,YM,SECCHI,IYEAR,MONTH,KD
   10 FORMAT(1X,2I2,2X,I3,I2,14X,F2.0,13X,2I2,24X,I1)
      IF(XD.LT.NLAT) GO TO 5
      IF(XD.GE.NLA) GO TO 5
      IF(YD.LT.NLONG) GO TO 5
      IF(YD.GE.NLO) GO TO 5
      IF(KD.GT.1) GO TO 5
      N=N+1
      IF(SECCHI.LT.0.1) GO TO 5
      IF(MONTH.EQ.0) GO TO 5
      IF(IYEAR.EQ.0) GO TO 5
      IF(MONTH.GT.12) GO TO 5
      IF(IYEAR.GT.72) GO TO 5
      N1=N1+1
      TOTSEC(IYEAR,MONTH)=TOTSEC(IYEAR,MONTH)+SECCHI
      DIVIDE(IYEAR,MONTH)=DIVIDE(IYEAR,MONTH)+1.0
      GO TO 5
   15 CONTINUE
      DO 30 IYEAR=1,72
      DO 25 MONTH=1,12
      IF(DIVIDE(IYEAR,MONTH).EQ.0.0) GO TO 25
      AVSEC(IYEAR,MONTH)=TOTSEC(IYEAR,MONTH)/DIVIDE(IYEAR,
     @MONTH)
   25 CONTINUE
   30 CONTINUE
      WRITE(6,50) N
   50 FORMAT('1',10X,'TOTAL NUMBER OF STATIONS.....',I5)
      WRITE(6,100) N1
  100 FORMAT('0',10X,'TOTAL NUMBER OF S-DEPTHS.....',I5)
      WRITE(6,150)
  150 FORMAT('0',20X,'TIME SERIES OF SECCHI MEASUREMENTS')
      DO 600 IYEAR=32,72
      MYEAR=0
      MYEAR=1900+IYEAR
      WRITE(6,200) MYEAR
  200 FORMAT('0',15X,'YEAR=',I4,//)
      WRITE(6,300)
  300 FORMAT('0',5X,'MONTH',5X,'NR. S-DEP',5X,'AVER. S-DEP')
      DO 500 MONTH=1,12
      WRITE(6,400) MONTH,DIVIDE(IYEAR,MONTH),AVSEC(IYEAR,
     @MONTH)
```

```
400 FORMAT(' ',6X,I2,10X,F4.0,11X,F4.1)
500 CONTINUE
600 CONTINUE
    STOP
    END
```

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation was made to determine possible correlations between Secchi depths and other simultaneously measured oceanographic parameters which were on file at the National Oceanographic Data Center as of March 1972. Sixty-three one-degree subsquares occurring in Japanese and Korean waters and eleven Atlantic and Pacific open ocean areas were chosen for linear correlation analysis using both sea surface data and mean

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values of some fourteen different oceanographic parameters averaged over the Secchi depth. In particular, oxygen measurements exhibited trends toward an inverse proportionality with Secchi depth while temperature data indicated aspossible direct proportionality.

Time series analyses of Secchi depths were performed and compared with upwelling indices computed for the Oregon coast and near Monterey Bay, California. An inverse proportionality and possible phase lag of mean Secchi depth compared to monthly upwelling index was observed. Multiple regression equations relating Secchi depth and upwelling index were calculated for both locations.